CERAM-SNA INC

H G

89-01948/

Centre de recherche
4125, rue Garlock
Sherbrooke (Québec)
Canada
J1L 1W9

Tél.: 819-566-5977
Télex: 05-836354
Télécopieur: 819-566-5383

Ceram-sna inc.
Filiale de la société nationale de l'amiante

HATSCHEK MACHINE TEST COMPARING WET VS DRY MILLED CASSIAR CHRYSOTILE

EXECUTIVE SUMMARY

by

M. Cossette, directeur, recherche technologique

Work on this project was conducted under the auspices of the Department of Energy, Mines and Resources.

DSS File number: 03SQ.23440-7-9176
DSS Contract number: 23440-7-9176/01-SQ
EMR Scientific Authority: D.M. Doyle

2 November 1988
series 17.115.585

MICROMEDIA

SIÈGE SOCIAL: 4125, rue Garlock,
Sherbrooke, Qué. J1L 1W9
Tél. (819) 566-5977

DISTRIBUTION

D.M. Doyle	(original and 2 copies) Energy, Mines and Resources CANMET, MSL Division 555 Booth Street Ottawa, Ontario K1A 0G1
Ms. A. Humphreys	Science Procurement Officer Department of Supplies and Services Science Branch 11 Laurier Street 11C1, Phase III Place du Portage Hull, QC K1A 0S5
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HATSCHEK MACHINE TESTS COMPARING WET VS DRY MILLED CASSIAR CHRYSOTILE

INTRODUCTION

A comparative evaluation of dry and wet milled Cassiar chrysotile was carried out by three methods; (1) Fibre Strength Unit tests that evaluate the strength imparting characteristics of fibres used to reinforce asbestos-cement flexural test specimens produced in the laboratory by filter pressing, (2) Production and testing of flat asbestos-cement panels made on a pilot scale Hatschek machine, and (3) Production and testing of asbestos-cement pipes made on a pilot scale Hatschek machine.

FIBRES EVALUATED

The following fibres were evaluated:

AK	dry milled chrysotile
AK-100	dry milled chrysotile
AX	dry milled chrysotile
AX-100	dry milled chrysotile
WX	wet milled chrysotile
WZ	wet milled chrysotile
4T	dry milled chrysotile

The latter was not produced by Cassiar and was included for comparison.

The degree of fiberization of the fibres received was determined by the Rapid Surface Area technique in ASTM Method D2752 and the fibre length distribution was determined by McNett wet classification ASTM Method D2589. The following results were obtained:

GRADE	RAPID SURFACE dm^2/g	MCNETT CLASSIFICATION +4M	-4 +16	-16 +40	-40 +100	-100 +200	-200	GEOMETRIC MEAN mm
*AK	47.1	27.8	23.0	13.7	6.8	3.5	25.2	1.075
*AK-100	107.9	32.3	24.0	13.9	6.6	2.6	20.6	1.390
*AX	45.1	2.7	19.7	33.0	11.9	3.6	28.2	0.537
*AX-100	101.2	4.6	20.1	34.3	11.7	4.0	25.3	0.609
WX	--	3.79	13.3	28.8	35.5	5.3	13.4	0.611
WZ	--	0.5	4.9	21.9	42.1	8.7	22.0	0.341
*4T	69.6	12.5	14.7	16.8	10.0	4.8	41.2	0.409

* after opening

METHODS OF FIBERIZATION

In addition to evaluations carried out on certain of the fibres as received (without any additional fiberization), some were evaluated after fiberization by one or more of the techniques described hereunder:

WILLOW: Fibres were fiberized by one pass through a 3-ft diameter Willow hammer mill with four rows of six hammers each at 1770r/min (185 rad/s).

PALLMANN: Fibres were treated with one pass through a Pallmann ModelL18 fiberizer without any retention ring, fitted with a style 5 abrading surface with 2.5mm sawtooth riffles at a 60 deg. angle of attack, at 6500r/min (681 rad/s).

TURBINE: Fibres were beaten in 500g aliquots of oven dried fibre dispersed in 20 dm^3 of diatomite-filtered water outgassed at 21°C and 76cmHg. The apparatus is shown in Fig. 1A with the exception that the impeller design shown in Fig. 1B was used. The slurry was beaten 30 min at 3450 r/min(361 rad/s).

FIG. 1A

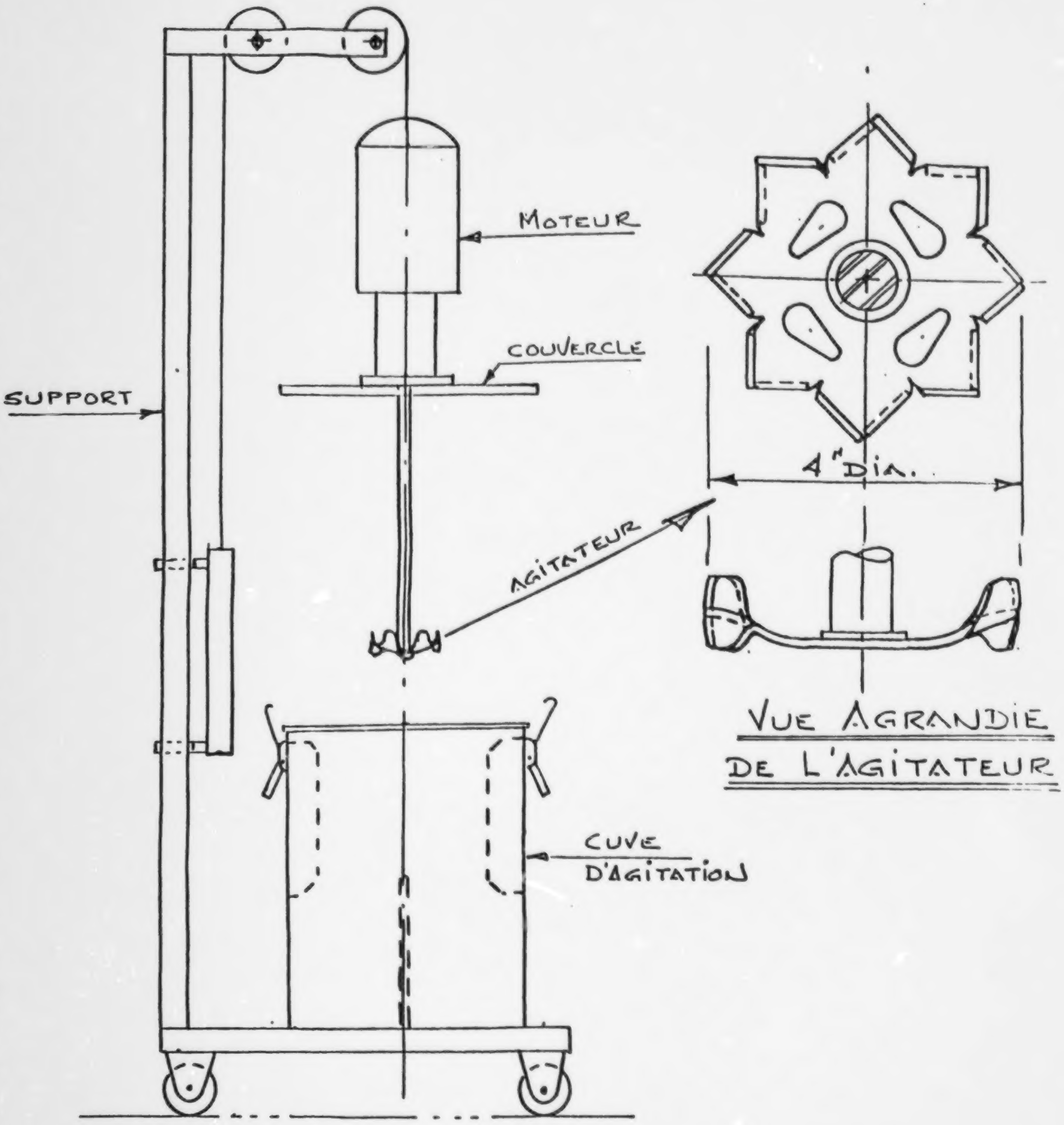

MOTEUR
COUVERCLE
SUPPORT
AGITATEUR
4" DIA.
VUE AGRANDIE DE L'AGITATEUR
CUVE D'AGITATION

FIG. 1A DÉFIBREUR À TURBINE

FIG. 1B

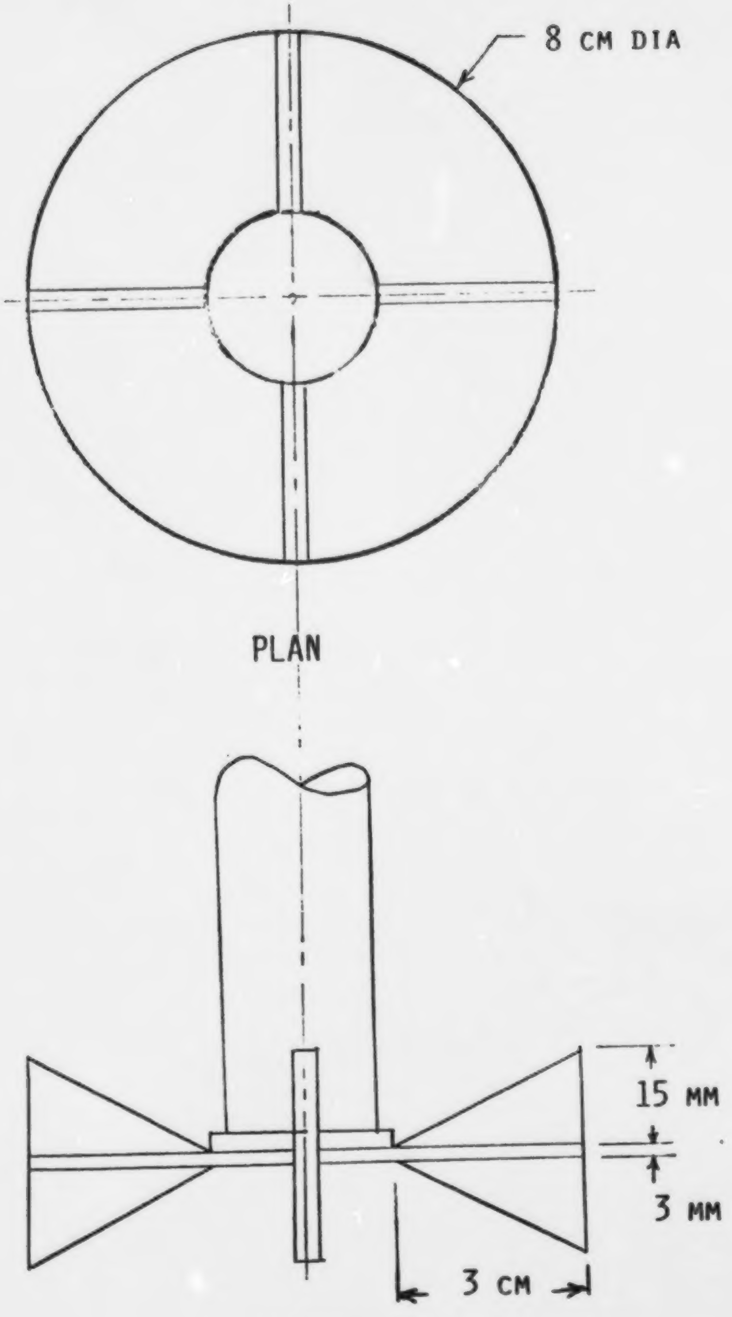

8 CM DIA
PLAN
15 MM
3 MM
3 CM
ELEVATION

Fig. 1B - TURBINE IMPELLER

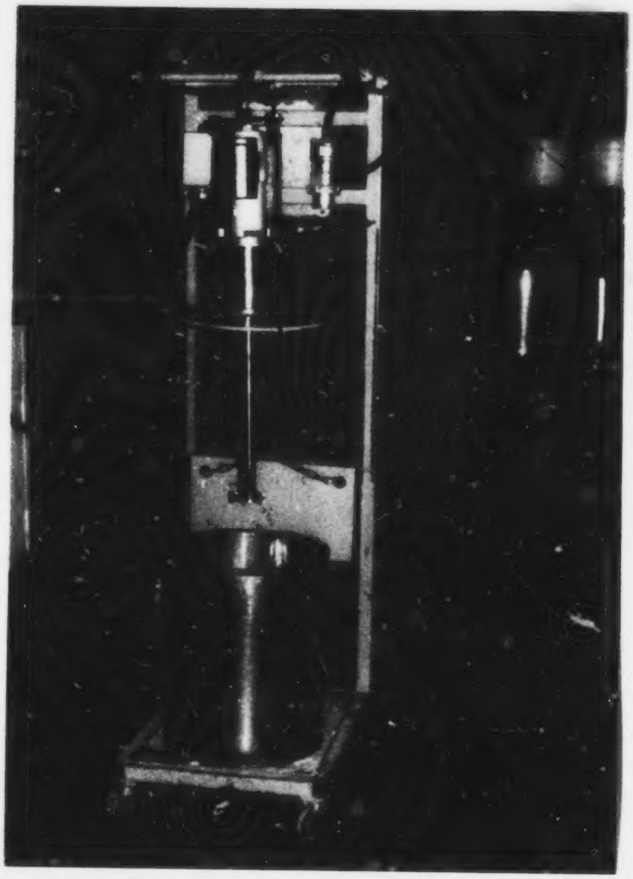


FIG. 1C Wet fiberizer
Open position

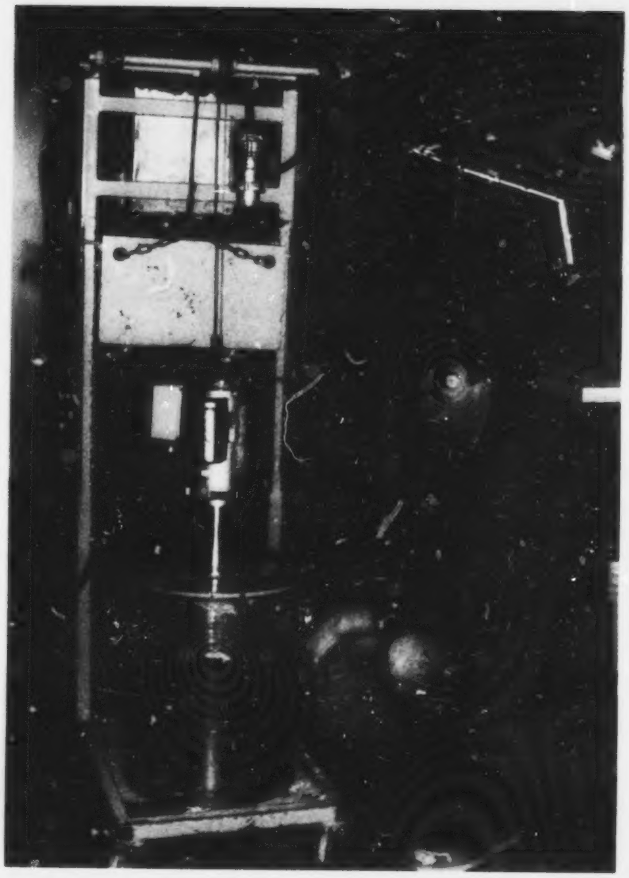


FIG. 1D Wet fiberizer
In operation

FIBRE STRENGTH UNIT EVALUATION

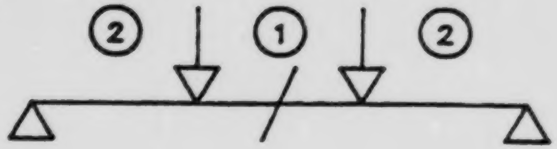
The standard ASTM Method D3880 was used to evaluate the fibre to estimate their reinforcing potential. The standard method was modified with regard to the fiberization of the fibres. The standard calls for 60 min. ball milling followed by two passed in a BOP fiberizer. That technique is adequate to determine the full theoretical reinforcing value of chrysotile asbestos fibres. However, it was desired to compare the fibres on the basis of a less than optimum degree of fiberization to reflect current industrial practice. Accordingly, the dry milled fibres were submitted to Willow fiberization and the wet milled fibres were tested as received without any further fiberization. The latest revision of Method D3880 was used that includes loading of the specimens equally and simultaneously at both one-third points of the span (Fig. 2.). The following results were obtained:

GRADE	FIBERIZATION	QF FIBRE RATIO %	POINT VALUE POINTS	MODIFIED FIBRE STRENGTH UNIT UNITS
AK-100	Willow	9	74	112
AK	Willow	9.3	70	108
AX-100	Willow	10	68	105
WX	as received	9.9	66	101
4T	Willow	11.7	54	85.5
WZ	as received	11.7	54	85.4
AX	Willow	16.1	36	60.0

In interpreting the above results, it must be kept in mind that the fibres were not fiberized to the optimum degree. The following relationship between Fibre Strength Unit (FSU) and geometric mean fibre length in μm holds except for the AX fibre: FSU= 23 ln (geometric mean, μm) -51

DETERMINATION DE LA RESISTANCE A LA FLEXION D'UNE EPROUVETTE CHARGEE AUX TIERS.

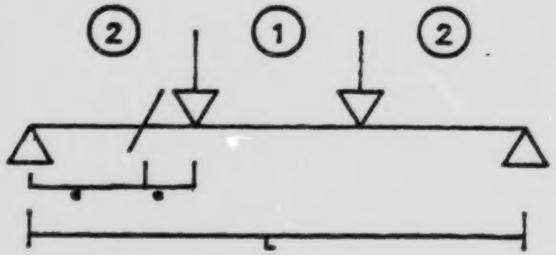
FORMULES :



R = module de rupture (kg)
P = charge maximum (kg)
L = portee (cm)
b = largeur moyenne (cm)
d = epaisseur moyenne (cm)

RUPTURE DANS ZONE 1 :

$$MRt = \frac{PL}{bd^2}$$



a = distance entre la ligne de rupture et l'appui le plus proche (cm).

RUPTURE DANS ZONE 2 :
si C/L ≤ 5%

$$MRt = \frac{3Pa}{bd^2}$$

$$MRa = \frac{MRt \times 2.56}{(Dt)^2}$$

MPa = 0.0980665 kg/cm2

Figure 2

The wet milled grades appear inferior in FSU to the AK-100, AK and AX-100. However, they are equal or better than the 4T and the AX.

EVALUATION IN AIR-CURED FLAT SHEETS

Comparative performance evaluation of five of the fibres was carried out by producing both pressed and non pressed air cured flat sheets of asbestos-cement, and determining their runability, density, porosity and flexural strength. The sheets were produced on a pilot scale Hatschek machine (see Fig. 3) and cured in saturated air. The following formulations were tried:

GRADE	FIBRE RATIO, %	CEMENT %
AK	8	92
WX	8	92
4T	10	90
WZ	10	90
AX	14	86

Runability was excellent in every case. The following production parameters were observed:

GRADE	AK	WX	4T	WZ	AX
Lamella/6mm thick	54	49	52	59	41
Feed consistency, g/dm^3	75	77	85	73	78
White water solids, g/dm^3	29	14	27	23	17

If the number of lamellae per 6mm of thickness is an indication of drainage speed for a given feed consistency, then as may be observed above, the drainage performance of the wet milled fibres was as good as that of the commercial dry milled comparison fibres. Note that this estimate of drainage speed was not confirmed by any measurement of drainage speed by an approved method as ASTM C1097.

The retention efficiency is indicated by the white water solids concentration. In every case the retention efficiency of the wet milled

FIG. 3 Overall view of the Hatschek machine pilote plant.

fibre was superior.

The dispersability of the wet milled fibres was observed to be superior to that of the comparison fibres. The WZ fibres were the best in this respect. The AK commercial dry milled fibres were the most resistant to dispersion during the wet mixing operation and this resulted in a product with a splotchy surface covered with the so-called asbestos flowers.

After curing in saturated moist air at room temperature for 28 days, these sheets were tested and the results are reported hereunder:

The flexural resistance of the flat sheets produced was determined by the third point loading technique on a 10cm span at a crosshead speed of 1mm/min. The specimens were tested in the saturated condition and in the machine and cross directions. The flexural moduli of rupture adjusted (MR_A) to a reference density of $1.6 g/cm^3$ are presented hereunder as the grand average flexural moduli of rupture for pressed and non pressed as well as for products tested in the machine and cross directions.

From the grand average results of adjusted flexural modulus of rupture (MR_A) for pressed and unpressed products tested in the machine and cross directions, the following conclusions can be arrived at:

The rankings in flexural strength in decreasing order are given hereunder:

FIBRE USED	ADJUSTED FLEXURAL MODULUS OF RUPTURE (MR_A)	
	MPa	psi
AK	43.8	6350
WX	38.8	5630
4T	37.6	5450
AX	36.4	5280
WZ	33.4	4840

However, if we take into account the fibre ratio used to arrive at the reinforcing efficiency, the rankings in decreasing order of efficiency are as follows:

FIBRE EVALUATED	STRENGTH MR_A, MP_a	FIBRE RATIO Qf,%	EFFICIENCY MR_A/Qf
AK	43.8	8	5.475
WX	38.8	8	4.85
4T	37.6	10	3.76
WZ	33.4	10	3.34
AX	36.4	14	2.60

It is apparent that the wet milled fibres are inferior in reinforcing efficiency to the AK, but superior to the AX.

The following densities and porosities were obtained:

GRADE	Qf FIBRE RATIO %	DENSITY, g/cm^3			POROSITY, %		
		NON PRESSED	PRESSED	AVG	NON PRESSED	PRESSED	AVG
WZ	10	1.62	1.87	1.75	24.8	16.6	20.7
WX	8	1.58	1.81	1.70	23.7	17.4	20.5
AX	14	1.46	1.80	1.63	28.3	17.8	23.1
AK	8	1.46	1.67	1.57	29.0	21.0	25.0
4T	10	1.41	1.65	1.53	30.6	20.6	25.6

The wet milled fibres yielded products that are significantly more dense and less porous for both pressed and non pressed air cured products.

EVALUATION IN AUTOCLAVED FLAT SHEETS

The comparative performance evaluation of all the fibres was carried out by producing both pressed and non pressed autoclaved flat sheets of asbestos-cement. The dry milled grades were fiberized in the Willow or Pallmann fiberizer. Wet milled grades were tried as received or as fiberized in the Pallmann or turbine. The sheets were produced on the same pilot scale Hatschek machine (Fig. 3). The dry ingredients (fibre, cement and silica) were premixed 15 min. in the vertical mixer. Felt speed was kept at 24m/min. The accumulator roll pressure was maintained at 11.5kg/cm. Products were cured by autoclaving 10h in saturated steam at 176.7°C and 0.82 MPa (100 psig or 115 psia). The pressed products were pressed 15 min. at 17.1 MPa (248 psi). The following formulations were tried:

FIBRE %	GRADE	FIBERIZATION	CEMENT %	SILICA %
8	AK	Willow	55.2	36.8
	AK-100	-		
	WX	as received		
10	WZ	as received	54	36
	4T	Willow		
14	AX	Willow	51.6	34.4
	AX-100	Willow		
	WX	as received		
	WZ	as received		
16	AX	Pallmann	50.4	33.6
	WX	Pallmann		
	WX	turbine		
	WZ	turbine		
18	AX	Willow	48	32
	WX	as received		
	WZ	as received		

The dry ingredients (fibre, cement and silica) were premixed in the noria for 15 min. Felt speed was 24m/min. The accumulator roll pressure was 11.5kg/cm. The pressed products were pressed 15 min. at 17.1 MPa (248 psi).

Runability was excellent in every case. The following production statistics were noted:

PARAMETER	RANGE			STANDARD
	Min.	Max.	Average	DEVIATION
Feed slurry consistency, %	5.9	7.8	7.1	0.5
White water concentration,%	0.66	2.25	0.96	0.44
Thickness, mm	8.3	9.6	8.9	0.4
Total number of plies	40	68	53	7
Number of plies/6mm	28	45	36	5
Plies/mm	4.6	7.5	6.0	0.8

The autoclaved products were tested in the same way as the air cured products and the grand average flexural moduli of rupture as tested (MR_T) and as adjusted to a reference density of 1.6g/cm³ (MR_A) for pressed and non pressed as well as for products tested in the machine and cross directions are presented hereunder.

				Average for pressed and non pressed		Grand average moduli of rupture	
Fibre %	Grade	Project	Fiber-ization	Density g/cm³	Porosity %	MR_T MPa	MR_A MPa
8	AK	initial	Willow	1.57	25.0	35.4	41.5
	AK-100	exten.	Willow	1.47	30.7	37.6	44.1
	WX	initial	as received	1.70	20.6	32.7	34.7

				Average for pressed and non pressed		Grand average moduli of rupture	
Fibre %	Grade	Project	Fiber-ization	Density g/cm³	Porosity %	MR_T MPa	MR_A MPa
10	WZ	initial	as received	1.75	20.7	36.5	34.6
	4T	both	Willow	1.53	25.6	26.5	34.2
14	AX	initial	Willow	1.63	20.8	34.9	39.6
	AX	exten.	Willow	1.47	29.4	37.4	43.7
	AX-100	exten.	Willow	1.53	26.7	36.2	39.5
	WX	exten.	as received	1.49	28.9	43.9	49.9
	WZ	exten.	as received	1.49	28.2	42.0	47.6
16	AX	exten.	Pallmann	1.51	28.6	40.6	44.7
	WX	exten.	Pallmann	1.46	30.1	47.1	55.5
	WX	exten.	turbine	1.49	29.4	46.9	53.1
	WZ	exten.	turbine	1.46	30.2	42.9	50.7
18	AX	exten.	Willow	1.43	31.4	42.4	52.3
	WX	exten.	as received	1.46	30.3	41.0	48.3
	WZ	exten.	as received	1.44	31.0	44.1	53.8

When compared against the dry milled fibres, the wet milled fibres gave comparable densities and porosities. The wet milled fibres as received yielded generally higher flexural strengths than dry milled fibres opened by one pass in a Willow. The anisotropy of sheets produced with wet milled fibre was significantly better in all cases and the ratios for tests in the machine and cross directions averaged as follows:

ANISOTROPY; MACHINE/CROSS DIRECTION

TYPE OF MILLING	MR_T Non pressed	MR_T Pressed	MR_T avg	MR_A Non pressed	MR_A Pressed	MR_A avg
Dry milled fibres	1.36	1.33	1.35	1.36	1.33	1.35
Wet milled fibres	1.27	1.25	1.27	1.27	1.25	1.26

When fibre efficiency is defined as the quotient of MR_A (in MP_a) divided by the fibre ratio (in %) the following average results were obtained:

FIBRE %	TYPE OF MILLING	AVERAGE FIBRE EFFICIENCY MP_a/%	Difference
8	dry (AK & AK-100)	5.4	-1.1
	wet (WX)	4.3	
10	dry (4T)	3.4	
	wet (WZ)	3.5	0.1
14	dry (AX-100&AX)	2.9	
	wet (WX & WZ)	3.5	0.6
16	dry (AX)	2.8	
	wet (WX & WZ)	3.3	0.5
18	dry (AX)	2.9	0.0
	wet (WX & WZ)	2.9	

In only one case (AK and AK-100 Vs WX at 8% fibre) did the dry milled fibre yield a superior efficiency.

Pallmann or wet turbine fiberization of the wet milled grades gave mixed flexural strength results but improved the anisotropy.

Based upon limited data, it appears that the wet milled fibres yield optimum and maximum flexural strength at the following fibre concentrations:

GRADE	FIBRE REQUIRED FOR FLEXURAL STRENGTH	
	OPTIMUM	MAXIMUM
WX	*8%	16%
WZ	*10%	**18%

*Lowest and **highest fibre concentrations tried. See Fig. 14, 15 & 16 for graphic presentations of MR_T and MR_A as a function of fibre ratio.

EVALUATION OF FIBRES IN PIPES

Production of the pipes

All the fibres were submitted to a comparison of their performance in autoclaved asbestos-cement pressure pipes. The dry milled fibres were tried with Willow fiberization and one grade, the AX, was also tried with Pallmann fiberization. Wet milled grades were tried as received or with Pallmann or turbine fiberization. Fibre to dry solids ratios of 14, 16 or 18% were used. The pipes were produced on a pilot scale Hatschek machine, illustrated in Fig. 4, 4A and 5 using 20.3-cm (8-in.) diameter mandrels shown in Fig. 6.

In each case, the binder (calcium silicate) was composed of normal (type 10) Portland cement and Sil-Co-sil silica flour (-120M) in the ratio of 3:2. The fibre cement and silica were dry blended 10 min in a drum mixer followed by 1 min wet premixing in a vertical mixer before final wet mixing in the ribbon blender. The following felt speeds and accumulator roll pressures were used:

PIPE No.	FELT SPEED		ACCUMULATOR ROLL PRESSURE	
	m/min	ft/min	kg/cm	lb/in
1 & 2	24	945	11.5	64.4
3	36	1417	11.5	64.4
4 to 6	13	512	23	129
7 to 40	17	669	23	129

In some cases, release from the mandrel was experienced before the required thickness was achieved. It was intended to produce pipes with wall thicknesses ranging between 19.7 and 21.2mm. However, this was impossible because of the mandrel release encountered. Commercial pipes are generally produced with a mixture of fibre grades that include one grade that can

Fig. 4 Asbestos-cement Class 100 pressure pipe production from wet milled chrysotile asbestos on a pilot plant scale Hatschek machine; overhead view from the wet end.

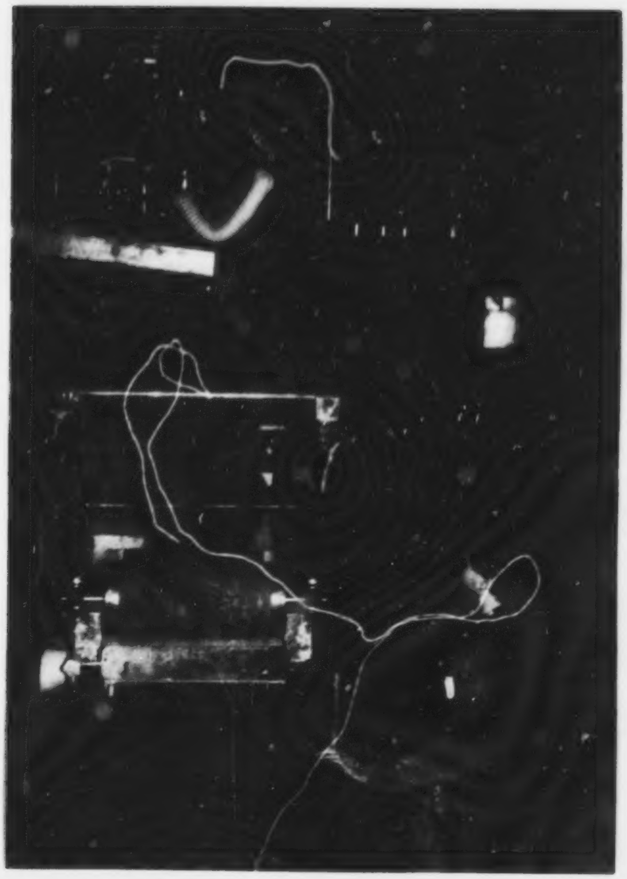


Fig. 4A Asbestos-cement Class 150 pressure pipe-production from wet milled chrysotile asbestos; viewed from the dry end.

FIG. 5 Eight-inch Class 150 asbestos-cement produced from wet milled chrysotile asbestos; on the mandrel at the mandrel removal stage.

FIG. 6

Two 8-in. Class 200 asbestos-cement high pressure pipes produced from wet milled chrysotile asbestos; on mandrels supported by a moist air curing rack.

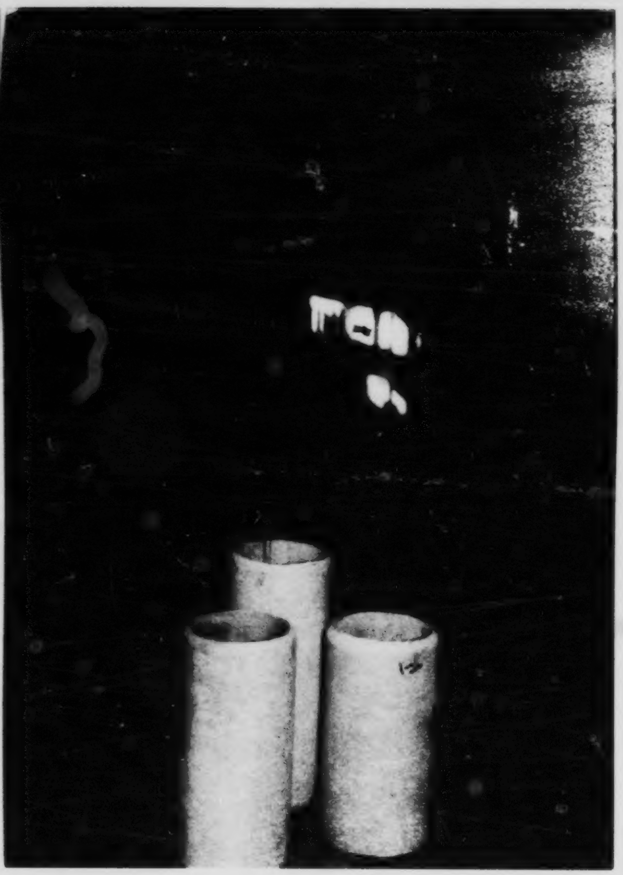


FIG. 7

Class 100 eight-inch autoclaved asbestos-cement pressure pipes produced from wet milled chrysotile asbestos by the Hatschek process promote resistance to plastic deformation (for example, crocidolite fibres may be used for this purpose).

The following pipe formulae were tried:

FIBRE GRADE	Qf, FIBRE RATIO, %	FIBERIZATION	PIPES PRODUCED, No.
AK	16	Willow	11,12 & Ref
AK-100	16	"	17,18 & 18R
AX	14	"	31 & 32
	16	Pallmann	29,30 & 30R
		Willow	7 & 8
	18	"	33 & 34
AX-100	16	"	19 & 20
WX	14	as received	21 & 22
	16	"	13 & 14
		Pallmann	25,25R&26
		turbine	27 & 28
	18	as received	23,24&24R
WZ	14	"	35 & 36
	16	"	15 & 16
		turbine	39 & 40
	18	as received	37,38 & 38R
4T	12	Willow	1,2 & 3
	16	"	4,5,6,9 & 10

The following pipe production parameters were observed:

PIPE PRODUCTION PARAMETERS

PIPE NO	GRADE	FIBERIZATION	OF FIBRE RATIO (%)	FEED SLURRY CONSISTENCY (%)	WHITE WATER CONCENTRATION (%)	THICKNESS (mm)	TOTAL NUMBER OF PLIES (N)	PLIES PER (mm) (N)	GREEN HARDNESS DUROMETER TYPE C
1	4T-30	WILLOW	12	9.9	2.40	16.6	105	6.3	---
2	4T-30	WILLOW	12	9.9	2.40	16.9	110	6.5	---
3	4T-30	WILLOW	12	8.1	3.10	15.5	134	8.6	36
4	4T-30	WILLOW	16	9.5	1.20	15.8	92	5.8	43
5	4T-30	WILLOW	16	---	----	----	---	---	---
6	4T-30	WILLOW	16	10.1	1.20	18.8	121	6.4	41
7	AX	WILLOW	16	10.3	1.50	14.5	77	5.3	39
8	AX	WILLOW	16	10.1	1.90	18.3	89	4.9	38
9	4T-30	WILLOW	16	8.9	1.10	12.7	69	5.4	52
10	4T-30	WILLOW	16	10.1	1.90	18.3	89	4.9	38
11	AK	WILLOW	16	9.3	1.70	19.0	103	5.4	44
12	AK	WILLOW	16	9.8	1.80	18.8	112	6.0	43
13	WX	AS RECEIVED	16	7.9	0.75	19.2	80	4.2	49
14	WI	AS RECEIVED	16	8.9	1.00	14.1	58	4.1	52
15	WZ	AS RECEIVED	16	9.1	0.85	16.8	80	4.8	36
16	WZ	AS RECEIVED	16	8.6	1.00	18.4	96	5.2	37
17	AK-100	WILLOW	16	5.3	0.98	21.7	162	7.5	43
18	AK-100	WILLOW	16	7.3	1.20	13.9	100	7.2	49
18R	AK-100	WILLOW	16	6.0	1.00	15.4	115	7.5	36
19	AX-100	WILLOW	16	8.5	1.10	18.6	126	6.8	29
20	AX-100	WILLOW	16	6.9	1.00	23.8	152	6.4	34
21	WX	AS RECEIVED	14	9.4	0.91	18.7	102	5.5	36
22	WX	AS RECEIVED	14	8.5	0.86	20.9	109	5.5	34
23	WX	AS RECEIVED	18	8.6	0.83	20.2	110	5.4	30
24	WX	AS RECEIVED	18	7.6	0.66	14.9	64	4.3	41
24R	WX	AS RECEIVED	18	6.5	0.60	18.2	100	5.5	35
25	WX	PALLMANN	16	6.5	0.64	18.4	101	5.5	36
25R	WX	PALLMANN	16	5.9	0.64	17.0	104	6.1	35
26	WX	PALLMANN	16	6.8	0.74	19.9	139	7.0	33
27	WX	TURBINE	16	7.9	0.51	18.3	108	5.9	32
28	WX	TURBINE	16	7.2	0.52	19.1	125	6.5	35
29	AX	PALLMANN	16	6.3	0.68	17.3	127	7.3	36
30	AX	PALLMANN	16	6.7	0.50	14.5	115	7.9	45
30R	AX	PALLMANN	14	7.3	0.83	20.6	190	9.2	30
31	AX	WILLOW	14	7.5	1.39	22.3	145	6.5	34
32	AX	WILLOW	18	5.9	1.11	22.6	144	6.4	31
33	AX	WILLOW	18	5.7	0.99	22.3	160	7.2	35
34	AX	WILLOW	18	5.4	0.83	22.9	152	6.6	35
35	WZ	AS RECEIVED	14	7.2	0.89	24.2	195	8.1	27
36	WZ	AS RECEIVED	14	6.8	0.98	17.9	148	8.3	29
37	WZ	AS RECEIVED	18	6.7	0.69	22.4	159	7.1	31
38	WZ	AS RECEIVED	18	6.1	0.62	15.6	109	7.0	37
38R	WZ	AS RECEIVED	18	7.2	0.45	19.7	94	4.8	27
39	WZ	TURBINE	16	7.0	0.67	16.4	118	7.2	29
40	WZ	TURBINE	16	10.5	0.47	16.7	66	4.0	32

The following production statistics were noted:

PARAMETER	RANGE MIN.	RANGE MAX.	AVERAGE	STANDARD DEVIATION
Feed slurry consistency, %	5.3	10.5	7.1	1.2
White water concentration, %	0.45	3.1	0.83	0.27
Thickness, mm	12.7	24.2	19.2	3.1
Total number of plies	58	195	122	37
Number of plies/mm	4.0	9.2	6.1	2.0
Green hardness, Durometer C	24	52	34	5

In order to estimate the magnitude of the plastic deformation obtained, the increase in length of the pipes was determined for pipes 17 to 40 as follows:

GRADE	PIPE NO.	FIBERIZATION	FIBRE %	LENGTH EXTENSION,cm
AK	Ref	Willow	16	0
AK-100	17,18,18R	Willow	16	0
AX	31,32,33,34	Willow	14 & 18	0
	29,30,30R	Pallmann	16	2.5
AX-100	19,20	Willow	16	2.0
WX	21,22	as received	14	3.5
	25,25R,26	Pallmann	16	3.8
	27,28	turbine	16	7.0
	23,24, 24R	as received	18	1.0
WZ	35,36	as received	14	5.5
	39,40	turbine	16	6.8
	37,38, 38R	as received	18	5.8

Length extension appears to vary proportionally with the degree of plastic deformation. The following remarks were noted with regard to runability:

GRADE	FIBERIZATION	FIBRE %	RUNABILITY
AK	Willow	16	Good runability
AK-100	Willow	16	"
AX	Willow	14	"
	Willow	16	Premature mandrel release
	Willow	18	Good runability
	Pallmann	16	Poor runability, premature mandrel release and plastic deformation
WX	as received	14	"
	"	16	"
	"	18	"
	Pallmann	16	"
	turbine	16	"
WZ	as received	14	"
	"	16	"
	"	18	"
	turbine	16	"
4T	Willow	16	good runability

The following remarks were noted during the production of the pipes:

GRADE	REMARKS
AK	Good fibre dispersion. Good runability.
AK-100	High feed slurry consistencies did not run well. The optimum consistency appears to be in the order of 6%.

GRADE	REMARKS
AX	Fiberized in the Willow: Good runability with 14 and 18% fibre. The premature mandrel release experienced with 16% fibre during the first project may be attributed to the shortage of +4mesh fibre in the AX received initially (for which the +4mesh McNett fraction was 45% lower as shown in Table 13 of the final report). Fiberized in the Pallmann: Premature mandrel release and 2.5cm of plastic deformation were noted. Again these shortcomings are attributed to the reduction in +4mesh fibre caused by Pallmann fiberization.
AX-100	Good runability. Some 2cm of plastic deformation was observed.
WX	Premature mandrel release was observed in all cases. Plastic deformation ranged between 1 and 7cm. The 1cm deformation was obtained with 18% fibre opened in the Willow, and this is acceptable. The 7cm extension resulted from the turbine wet fiberized product.
WZ	Premature mandrel release was observed. Plastic deformation average 5.7 cm for fibres as received and 6.8 cm for fibres opened wet in the turbine.

The pipes were autoclaved 10h in saturated steam at 176.7°C and 0.82MPa (100 psig or 115 psia).

TESTING OF THE PIPES

The pipes (Fig.7) were tested for resistance to crushing (Fig. 8, 9 & 10) and to hydrostatic pressure (Fig. 11, 12, & 13) in accordance with ASTM Methods C500. In view of the insufficient pipe wall thicknesses produced, the crushing and hydrostatic strengths per cm of thickness were calculated to permit their performance classification. Average pipe densities and porosities were also measured and are presented hereunder together with the crushing and hydrostatic strengths per cm of thickness.

The crushing and hydrostatic resistance requirements of ASTM Specification C296 for 20.3-cm (8-in.) asbestos-cement pressure pipe are as follows:

CLASS	HYDROSTASTIC PROOF PRESSURE psi	MPa	MINIMUM CRUSHING LOAD lbf/ft	kN/m
100	350	2.41	4000	58.4
150	525	3.62	5500	80.3
200	700	4.83	9300	135.7

Based upon the maximum wall thickness for 20.3-cm(8-in.) pipe of 2.12cm the corresponding minimum hydrostatic and crushing requirements are as follows:

CLASS	HYDROSTATIC PROOF PRESSURE PER mm OF THICKNESS MPa/cm	MINIMUM CRUSHING LOAD PER mm OF THICKNESS kN/m.cm
100	1.14	27.5
150	1.71	37.9
200	2.28	64.0

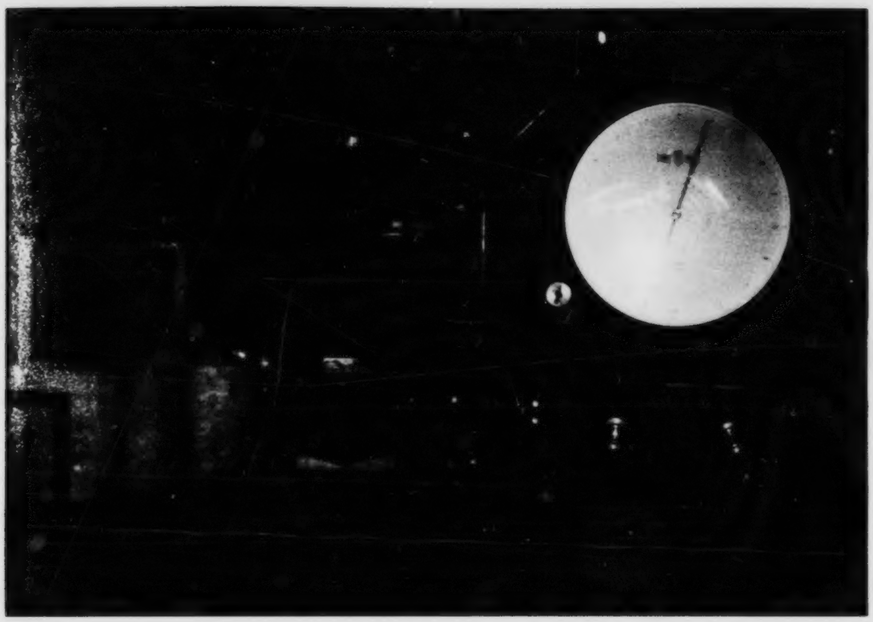


FIG. 8 Press and dynamometer used to determine the crushing strength of pipes in accordance with ASTM Method C500. The eight-inch asbestos-cement high pressure Class 200 pipe specimens shown on the left were produced from wet milled chrysotile asbestos.

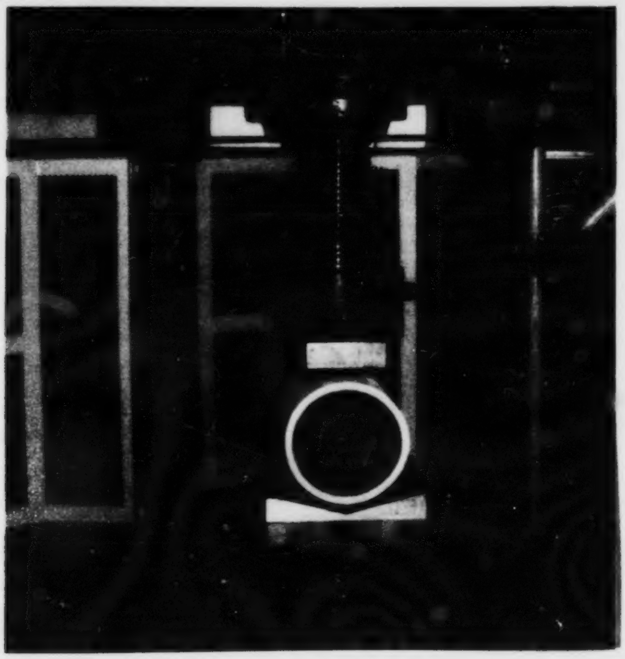


FIG. 9 Class 100 eight-inch asbestos-cement pressure pipe produced from wet milled chrysotile mounted in the press for the determination of crushing strength.

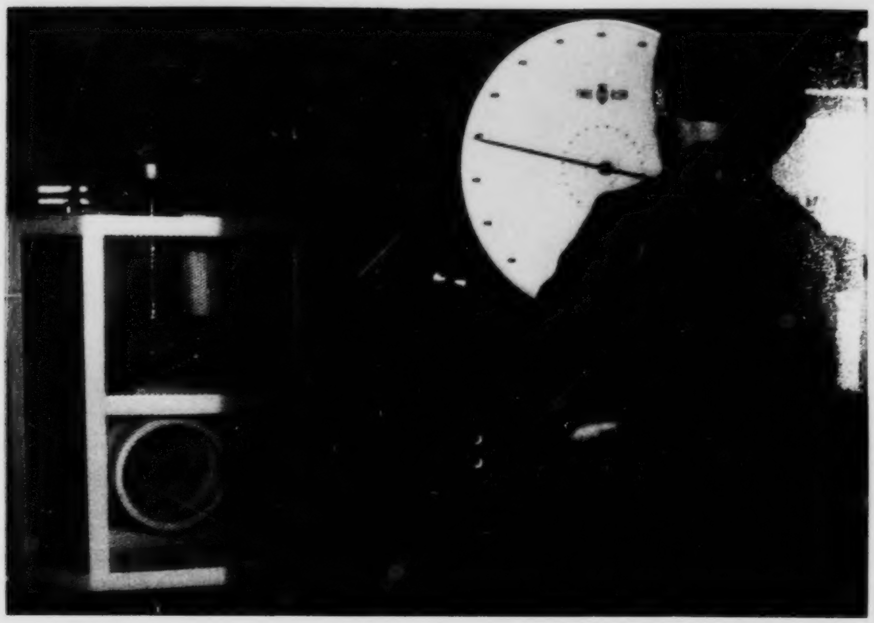


FIG. 10 Class 200 eight-inch high pressure asbestos-cement pipe produced from wet milled chrysotile asbestos undergoing a crushing strength determination in acordance with ASTM Method C500. This specimen eventually broke under a crushing load of 135 kN/m (9246 lbf/lineal foot).

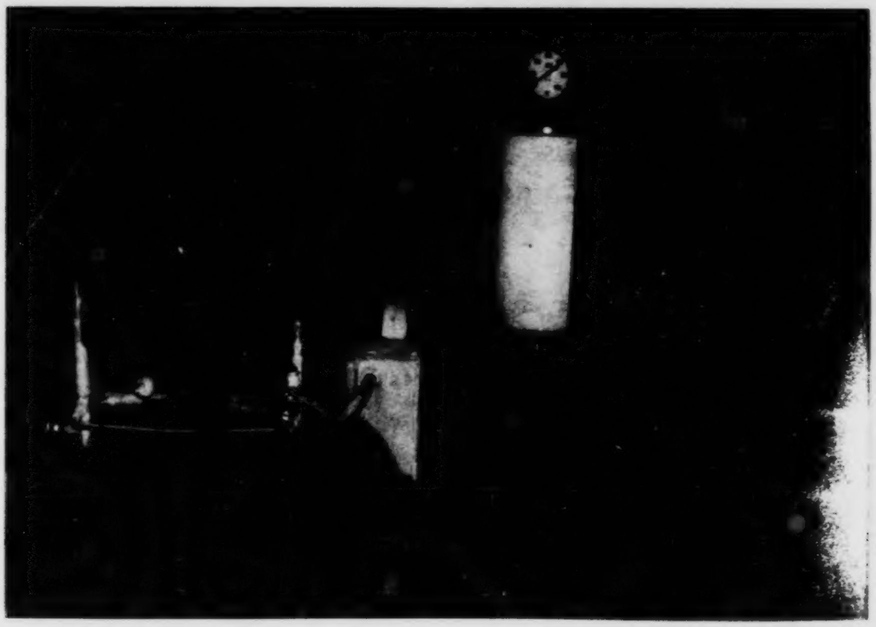


FIG. 11 Hydrostatic pressure testing system for testing asbestos-cement pressure pipes in accordance with ASTM Method C500.

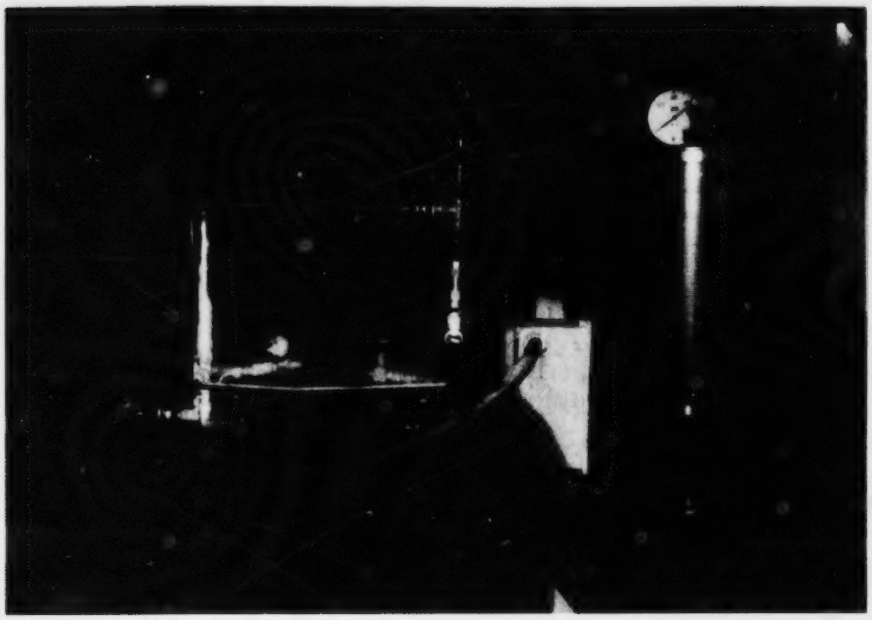


FIG. 12 Class 100 eight-inch asbestos-cement pressure pipe undergoing hydrostatic pressure testing. The pipe specimen which was produced from wet milled chrysotile asbestos is located inside the gray perforated steel cylindrical guard shield at the right.

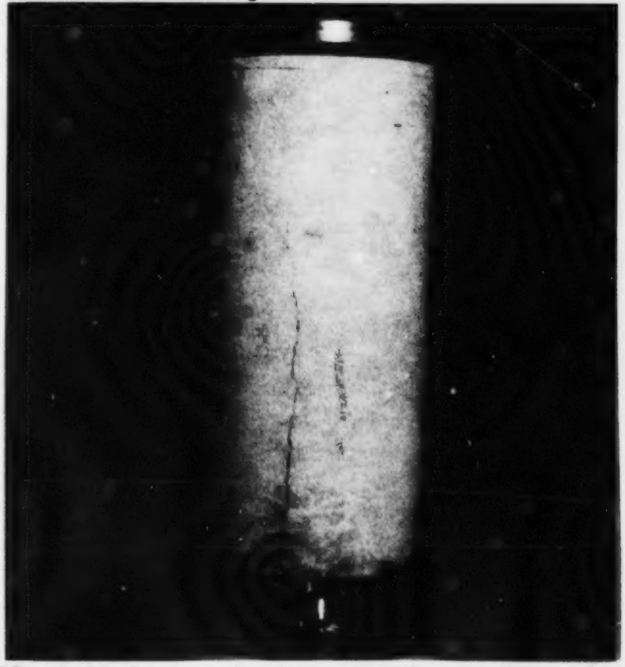


FIG. 13 Class 100 eight-inch asbestos-cement pressure pipe after breaking under a hydrostatic pressure of 3.4kPa (493 psi). This pipe was produced from wet milled chrysotile asbestos.

PIPE TEST RESULTS

						PER cm OF THICKNESS	
GRADE	PIPE No.	FIBERIZATION	FIBRE RATIO (%)	DENSITY g/cm3	POROSITY (%)	CRUSHING STRENGTH kN/m.cm	HYDROSTATIC STRENGTH MPa/cm
AK	11	WILLOW	16	1.51	26	69	---
	12	WILLOW	16	1.42	31	75	---
	REF	WILLOW	16	1.39	31	76	>2.34
AK-100	17	WILLOW	16	1.39	31	68	>2.20
	18	WILLOW	16	1.47	29	46	---
	18R	WILLOW	16	1.47	29	---	1.79
AX	31	WILLOW	14	1.52	25	62	>2.19
	32	WILLOW	14	1.49	27	57	---
	7	WILLOW	16	1.56	25	51	---
	8	WILLOW	16	1.60	23	---	2.22
	29	PALLMANN	16	1.43	30	43	---
	30	PALLMANN	16	1.52	26	---	2.08
	30R	PALLMANN	16	1.49	28	---	1.99
	33	WILLOW	18	1.45	28	66	---
	34	WILLOW	18	1.44	29	59	>2.19
AX-100	19	WILLOW	16	1.53	26	59	---
	20	WILLOW	16	1.50	27	---	1.76
WX	21	AS RECEIVED	14	1.48	28	41	---
	22	AS RECEIVED	14	1.49	27	---	0.59
	13	AS RECEIVED	16	1.49	28	---	>2.55
	14	AS RECEIVED	16	1.47	28	44	---
	25	PALLMANN	16	1.42	31	---	1.74
	25R	PALLMANN	16	1.43	30	---	1.83
	26	PALLMANN	16	1.38	32	41	---
	27	TURBINE	16	1.38	33	---	0.38
	28	TURBINE	16	1.38	32	34	---
	23	AS RECEIVED	18	1.42	31	36	---
	24	AS RECEIVED	18	1.41	31	---	1.74
	24R	AS RECEIVED	18	1.43	30	---	1.97
WZ	35	AS RECEIVED	14	1.44	28	51	---
	36	AS RECEIVED	14	1.47	28	---	1.72
	15	AS RECEIVED	16	1.47	28	---	---
	16	AS RECEIVED	16	1.53	26	---	---
	39	TURBINE	16	1.35	33	31	---
	40	TURBINE	16	1.36	34	---	0.47
	37	AS RECEIVED	18	1.38	31	---	1.15
	38	AS RECEIVED	18	1.39	32	50	---
	38R	AS RECEIVED	18	1.31	35	39	---
4T-30	4	WILLOW	16	1.52	27	---	---
	9	WILLOW	16	1.57	24	---	---
	10	WILLOW	16	1.47	29	54	>2.46

On that basis, the pipes were classified as follows:

CLASSIFICATION OF PIPES

GRADE	PIPE NO	FIBERIZATION	FIBRE RATIO (%)	THICKNESS cm	RESISTANCE PER UNIT THICKNESS CRUSHING kN/m.cm	 CLASS	 BURSTING MPa/cm	 CLASS	CLASSIFICATION CLASS
AK	11	WILLOW	16	1.95	69.1	200	---	---	200
	12	WILLOW	16	1.93	74.9	200	2.49	---	200
	REF	WILLOW	16	2.05	75.9	200	2.34	200	200
AK-100	17	WILLOW	16	2.18	67.8	200	>2.20	200	200
	18	WILLOW	16	1.39	46.1	150	---	---	150
	18R	WILLOW	16	1.51	---	---	1.79	150	150
AX	31	WILLOW	14	2.19	62.0	150	>2.19	200	150
	32	WILLOW	14	2.25	57.2	150	---	---	150
	7	WILLOW	16	1.49	51.2	150	---	---	150
	8	WILLOW	16	1.85	---	---	2.22	150	150
	33	WILLOW	18	2.24	66.1	200	---	---	200
	34	WILLOW	18	2.19	58.5	150	---	---	150
	29	PALLMANN	16	1.71	43.3	150	>2.19	200	150
	30	PALLMANN	16	1.30	---	---	2.08	150	150
	30R	PALLMANN	16	2.06	---	---	1.99	150	150
AX-100	19	WILLOW	16	1.62	59.2	150	---	---	150
	20	WILLOW	16	2.38	---	---	1.76	150	150
WX	21	AS RECEIVED	14	1.85	40.6	150	---	---	150
	22	AS RECEIVED	14	2.05	---	---	0.59	(a)	(a)
	13	AS RECEIVED	16	1.88	---	---	>2.55	200	200
	14	AS RECEIVED	16	1.29	44.2	150	---	---	150
	23	AS RECEIVED	18	1.95	36.0	100	---	---	100
	24	AS RECEIVED	18	1.44	---	---	1.74	150	150
	24R	AS RECEIVED	18	1.83	---	---	1.97	150	150
	25	PALLMANN	16	1.55	---	---	1.74	150	150
	25R	PALLMANN	16	1.75	---	---	1.83	150	150
	26	PALLMANN	16	1.95	41.4	150	---	---	150
	27	TURBINE	16	1.86	---	---	0.38	(a)	(a)
	28	TURBINE	16	1.86	34.2	100	---	---	100
WZ	35	AS RECEIVED	14	2.40	50.5	150	---	---	150
	36	AS RECEIVED	14	1.63	---	---	1.72	150	150
	37	AS RECEIVED	18	2.34	---	---	1.15	100	100
	38	AS RECEIVED	18	1.51	49.9	150	---	---	150
	38R	AS RECEIVED	18	2.02	39.2	150	---	---	150
	39	TURBINE	16	1.59	31.2	100	---	---	100
	40	TURBINE	16	1.70	---	---	0.47	(a)	(a)
4T-30	10	WILLOW	16	1.95	53.7	150	2.45	200	150

CONTROL LIMITS FOR 8-in. (20.3-cm) PIPE

---	---	---	---	1.97 TO 2.12	27.5	100	1.13	100	100
---	---	---	---	1.97 TO 2.12	37.8	150	1.70	150	150
---	---	---	---	1.97 TO 2.12	64.1	200	2.26	200	200

* DATA FROM INITIAL PROJECT

(a) INSUFICIENT THICKNESS (less than 0.5in)

It should be noted that the maximum bursting pressure generated by the test apparatus was 4.8 MPa and pipes that did not break at this pressure were assigned the class 200 without taking their thickness into account. The best results for all the fibres are summarized below:

					BASED ON RESISTANCE TO:		
GRADE	FIBERIZATION	FIBRE RATIO %	PIPE No.	THICKNESS cm	CRUSHING CLASS	HYDROSTATIC CLASS	OVERALL CLASS
AK	Willow	16	12	1.93	200	200	200
AK-100	Willow	16	17	2.18	200	200	200
AX	Willow	14	31	2.19	150	200	150
		18	33	2.24	200	--	
AX-100	Willow	16	19	1.62	150	--	150
			20	2.38	--	150	--
WX	as received	16	13	1.88	--	200	150
			14	1.29	150	--	--
WZ	as received	14	35	2.40	150	--	150
			36	1.63	--	150	--
4T	Willow	16	10	1.95	150	200	150

CONCLUSIONS

1. The modified Fibre Strength Unit (FSU) evaluation indicates that the wet milled grades are inferior in FSU to the AK-100, AK and AX-100. However, they are equal or better than the 4T and the AX. It must be kept in mind that the fibres were not fiberized to their optimum degree as called for by the standard FSU method.

2. The evaluation based upon air cured flat sheets showed that the wet milled fibres gave excellent runability on the Hatschek machine.

   The following rankings, in decreasing order of flexural strength were revealed: AK, WX, 4T, AX and WZ.

   The rankings in decreasing order of fibre efficiency were: AK, WX, 4T, WZ and AX.

   Wet milled fibres yielded products that are significantly more dense and less porous that are expected to have superior durability.

3. The evaluation based upon autoclaved flat sheets indicated good runability with the wet milled fibres.

   When compared against the dry milled fibres, the wet milled fibres gave comparable densities and porosities.

   The wet milled fibres as received yielded generally higher flexural strengths than the dry milled fibres opened by one pass in a Willow (See Fig. 14 to 16).

   The anisotropy of sheets produced with wet milled fibre was significantly better in all cases.

   In only one case (AK or AK-100 Vs WX at 8% fibre) did the dry milled fibre yield a superior fibre efficiency.

Pallmann or wet turbine fiberization of the wet milled grades gave mixed flexural strenth results but improved the anisotropy.

4. The pipe evaluation indicated poor runability, premature mandrel release and plastic deformation with the wet milled fibres. This was attributed to the use of only one grade in the fibre mix. Commercial pipes are generally produced with a mixture including one grade that can promote resistance to plastic deformation (such as crocidolite).

   The following ranking in decreasing order of runability was observed: AK-100, AK, AX, 4T, AX-100, WX and WZ.

   The pipe densities obtained on the pilot machine ranged between 1.3 and 1.6g/cm^3 compared against 1.7 to 1.9g/cm^3 obtained on industrial scale machines. Low densities have a detrimental effect on strength but all the fibres were compared on the same basis. Only the classification of the pipes may be affected.

   The following ranking in decreasing order of crushing and hydrostatic resistance was obtained: AK, AK-100, 4T, AX, AX-100, WX and WZ.

   At each fibre ratio level, the wet milled fibre gave inferior crushing and bursting strengths. However, it must be kept in mind that the comparison fibres are among the best and the wet milled fibres were able to yield class 150 pipes despite low density, and the absence of harsh fibre in the furnish.

FIG. 14

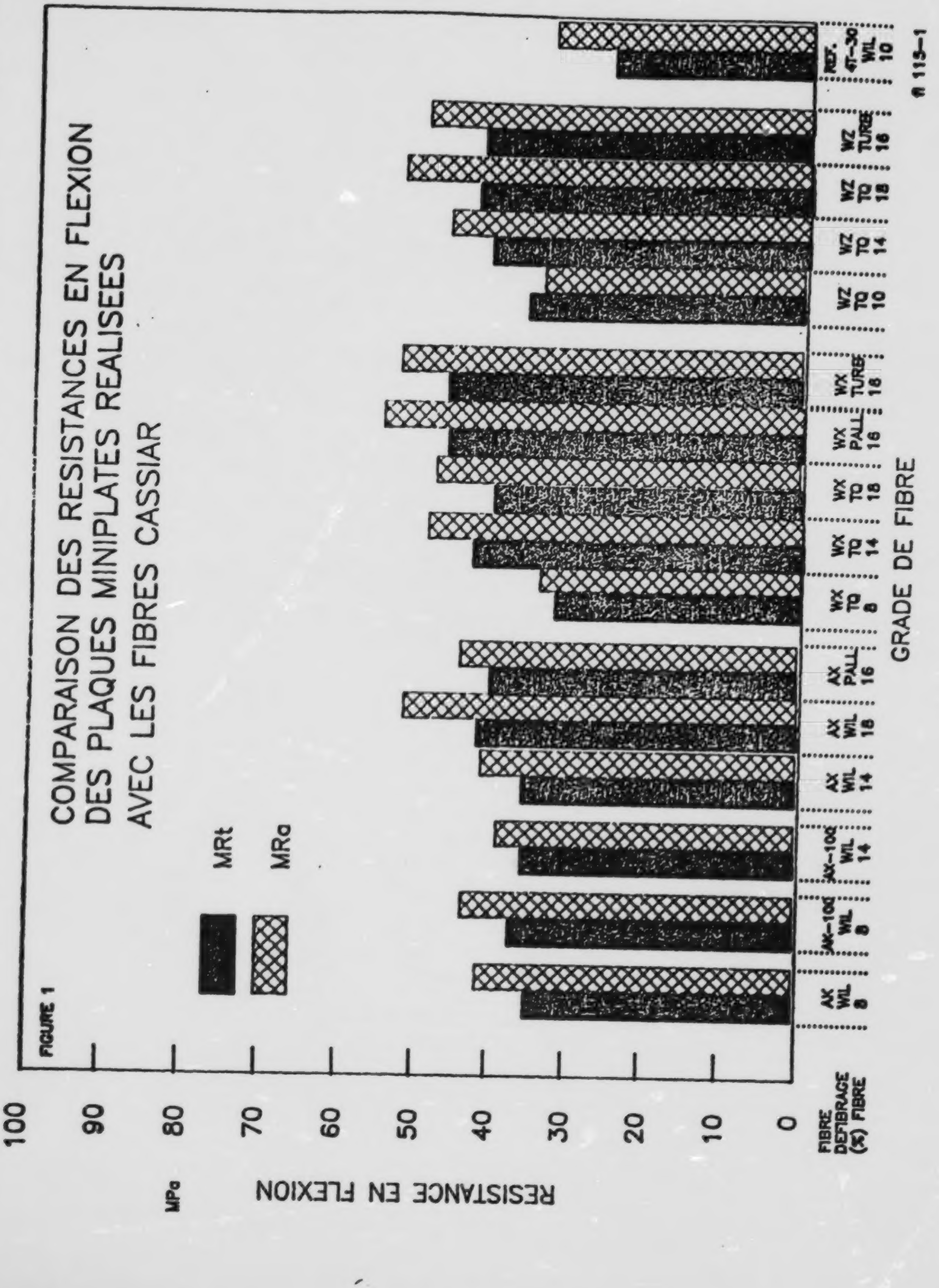


FIGURE 1
COMPARAISON DES RESISTANCES EN FLEXION
DES PLAQUES MINIPLATES REALISEES
AVEC LES FIBRES CASSIAR
MRt
MRa
MPa
RESISTANCE EN FLEXION
100
90
80
70
60
50
40
30
20
10
0
FIBRE
DEFIBRAGE
(%) FIBRE
AX WIL 8
AX-100 WIL 8
AX-100 WIL 14
AX WIL 14
AX WIL 18
AX PALL 16
WX TO 8
WX TO 14
WX TO 18
WX PALL 16
WX TURB 18
WZ TO 10
WZ TO 14
WZ TO 18
WZ TURB 16
REF. 4T-30 WIL 10
GRADE DE FIBRE
# 115-1

Fig. 15

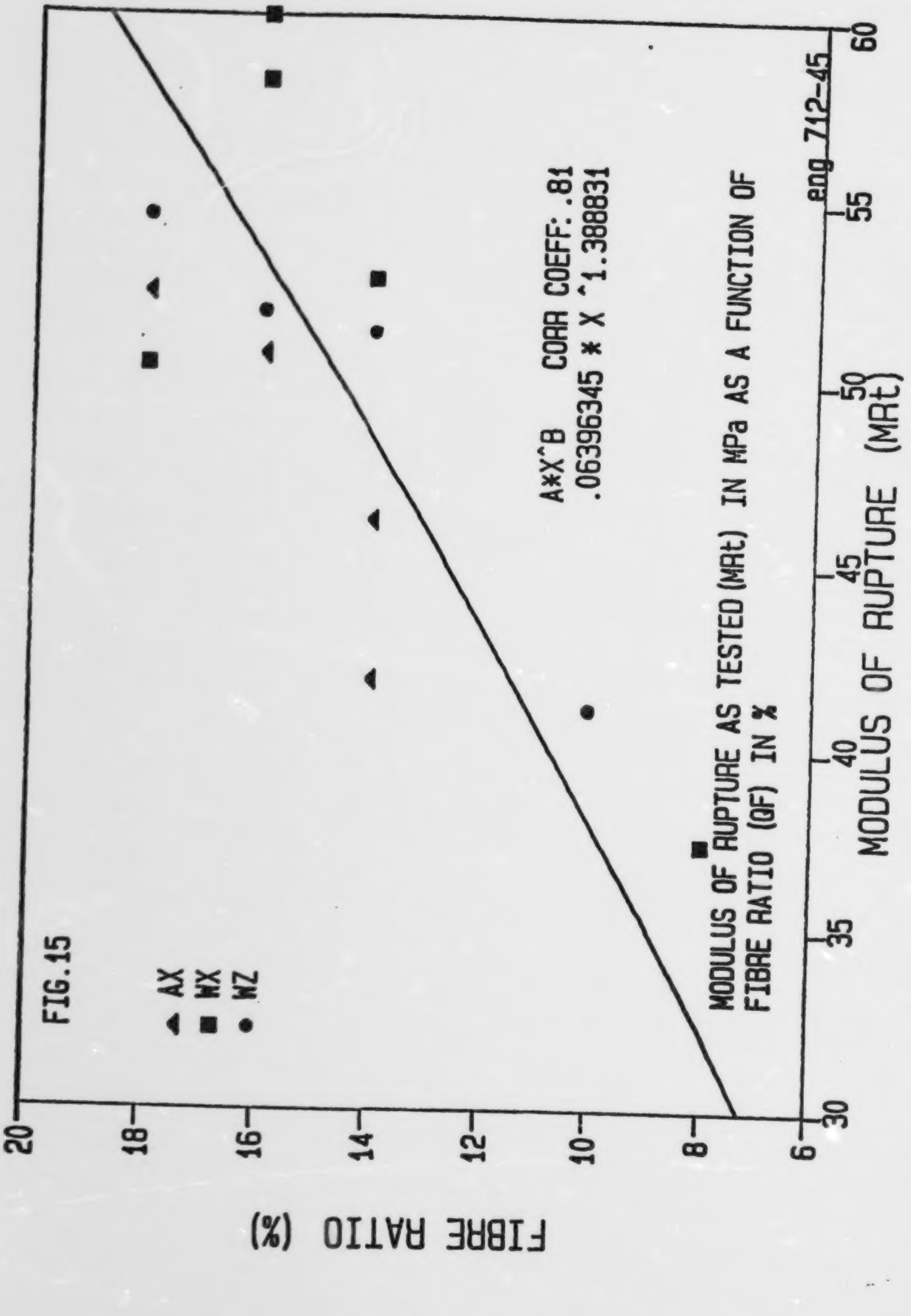
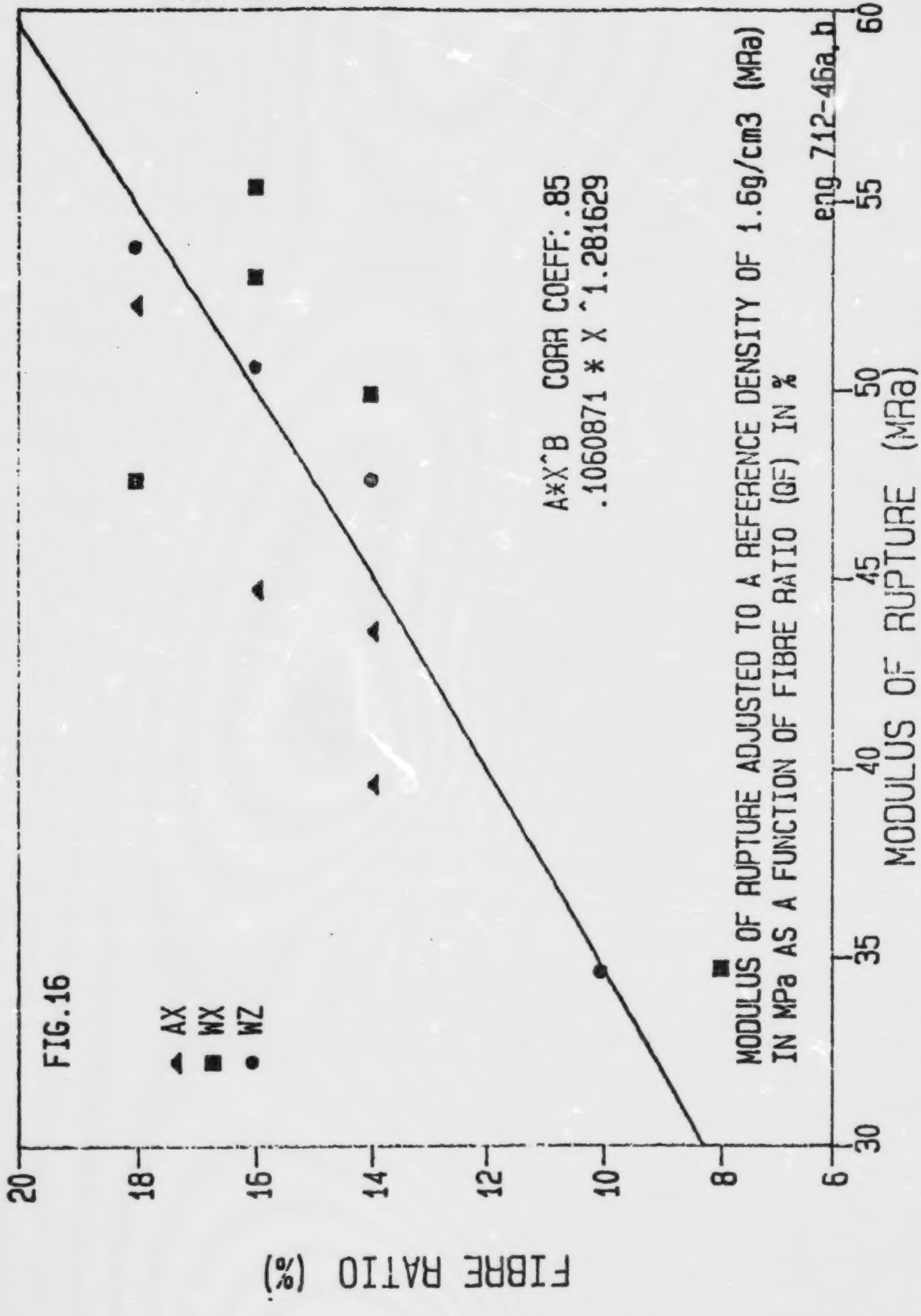


FIG.15
▲ AX
■ WX
● WZ
A*X^B CORR COEFF: .81
.06396345 * X ^1.388831
MODULUS OF RUPTURE AS TESTED (MRt) IN MPa AS A FUNCTION OF
FIBRE RATIO (QF) IN %
eng 712-45
FIBRE RATIO (%)
MODULUS OF RUPTURE (MRt)
20
18
16
14
12
10
8
6
30
35
40
45
50
55
60

FIG. 16



MODULUS OF RUPTURE ADJUSTED TO A REFERENCE DENSITY OF 1.6g/cm3 (MPa) IN MPa AS A FUNCTION OF FIBRE RATIO (GF) IN %

RECOMMENDATION

Evaluate the wet milled fibres as components of an industrial pipe furnish (fibre mix) including fibres that contribute resistance to plastic deformation.

CERAM-SNA INC

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Centre de recherche
4125, rue Garlock
Sherbrooke (Québec)
Canada
J1L 1W9

Tél.: 819-566-5977
Télex: 05-836354
Télécopieur: 819-566-5383

Ceram-sna inc.
Filiale de la société nationale de l'amiante

HATSCHEK MACHINE TEST COMPARING WET VS DRY MILLED ASBESTOS FIBRES FOR ASBESTOS-CEMENT APPLICATION

FINAL REPORT

by

M. Cossette, directeur, recherche technologique

V.H.Tran, Research Engineer,

Ceram-sna inc.

Work on this project was conducted under the auspices of the Department of Energy, Mines and Resources.

DSS File number: 03SQ.23440-7-9176
DSS Contract number: 23440-7-9176/01-SQ
EMR Scientific Authority: D.M. Doyle

15 August 1988
series 16.115.581

129 pp

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Sherbrooke, Qué. J1L 1W9
Tél. (819) 566-5977

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PROJET INITIAL

SOMMAIRE

Phase 1, partie 1:

1. Des essais de résistance flexurale furent exécutés sur les fibres suivantes parmi lesquelles le WX et le WZ étaient des fibres produites par voie humide qui ne reçurent aucun défibrage additionnel.

CLASSE		
AK	Résistance 109	FSU
WX	101	
4T	86	
WZ	83	
AX	62	

Il fut conclu que les fibres produites par voie humide étaient de résistance intermédiaire entre le AK et le AX.

Phase 1, partie 2:

Des feuilles d'amiante-ciment planes furent produites sur machine Hatschek pilote et mûries par autoclavage. Les formules comparées furent:

CLASSE	FIBRE, %	CIMENT, %	SILICE, %
AK	8	55.2	36.8
WX	8	55.2	36.8
4T	10	54	36
WZ	10	54	36
AX	14	51.6	34.4

La mise en oeuvre fut excellente de toutes façons pour toutes les fibres. Les densités et porosités obtenues furent:

CLASSE	DENSITE g/cm³	DENSITE lb/pi³	POROSITE %
WZ	1.54	96	28
WX	1.45	91	30
AX	1.38	86	33
AK	1.34	84	35
4T	1.29	81	39

Les fibres produites par voie humide ont produit des densités et porosités plus avantageuses et il est prévu qu'elles pourraient permettre des produits plus durables.

Les moyennes des résultats de résistance flexurale en direction machine, direction transversale, comprimée et non comprimée sont telles que suit:

CLASSE	MODULE DE RUPTURE FLEXURALE AJUSTEE MP$_a$	PSI
AK	41.8	6060
AX	39.6	5740
WZ	34.7	5080
WX	34.6	5060
4T	34.1	4950

Il fut conclu que les fibres produites par voie humide étaient légèrement inférieures, mais bien adéquates, en résistance flexurale. Cependant, si nous tenons compte des teneurs en fibres utilisées, les fibres produites par voie humide donnent une performance comparable. Voir Table 8A.

Phase 1, partie 3

Des feuilles planes furent produites sur machine Hatschek pilote et mûries en air saturée d'humidité durant 28 jours. Les formules suivantes furent essayées:

CLASSE	FIBRE, %	CIMENT, %
AK	8	92
WX	8	92
4T	10	90
WZ	10	90
AX	14	86

La mise en oeuvre fut excellente de toutes façons pour toutes les fibres. Les densités et porosités obtenues furent:

CLASSE	DENSITE g/cm³	DENSITE lb/pi³	POROSITE %
WZ	1.62	101	24.8
WX	1.58	99	23.7
AX	1.46	91	28.3
AK	1.46	91	29.0
4T	1.41	88	30.6

Les produits mûris à l'air saturée des fibres produites par voie humide se sont avérés supérieurs sur les plans de la densité et de la porosité

Les moyennes des résistances flexurales en direction machine, direction transversale, pressées et non pressées furent telles que suit:

CLASSE	MODULE DE RUPTURE FLEXURALE AJUSTE MP_a	MODULE DE RUPTURE FLEXURALE AJUSTE PSI
AK	43.8	6353
WX	38.8	5626
4T	37.4	5453
AX	36.4	5279
WZ	33.4	4844

Cependant, si nous tenons compte de la proportion des fibres utilisées pour obtenir leur efficacité de renforcissement, les rangs suivants sont obtenus:

CLASSE	RESISTANCE MR_A, MPa	PROPORTION DE FIBRE Qf, %	EFFICACITE MR_A/Qf
AK	43.8	8	5.48
WX	38.8	8	4.85
4T	37.6	10	3.76

(suite)

CLASSE	RESISTANCE MR_A, MP_a	PROPORTION DE FIBRE Qf, %	EFFICACITE MR_A/Qf
WZ	33.4	10	3.34
AX	36.4	14	2.60

Les résultats obtenus pour les feuilles planes mûries à l'air saturée indiquent que les fibres produites par voie humide sont inférieures au AK mais supérieures au AX. Les résultats pour les produits mûris à l'air saturée sont légèrement inférieurs (après 28 jours) à ceux des produits autoclavés, mais ils sont généralement similaires.

Phase 2 (tuyaux)

La mise en oeuvre fut excellente sauf en ce qui concerne la déformation plastique observée particulièrement avec les trois classes de fibres les plus courtes AX, WX et WZ. Ceci n'est pas inattendu vu que des mélanges de fibres incluant des fibres qui confèrent la résistance à la déformation plastique ne furent pas utilisées dans l'alimentation (chaque fibre fut essayée seule).

Les densités de tuyaux obtenus, 1.4 à 1.6g/cm^3, furent significativement inférieures aux densités qui peuvent être obtenues sur machine Hatschek à l'échelle industrielle (1.7 à 1.9g/cm^3) et une densité inférieure peut nuire à la porosité, la résistance à l'écrasement et la résistance hydrostatique.

Des porosités allant de 23 à 31% furent obtenues pour les tuyaux et ces porosités variaient inversement avec les densités obtenues.

Les résistances à l'écrasement calculées pour des épaisseurs équivalentes au domaine entre 19.7 et 21.2cm sont suffisantes pour la Classe 100 dans tous les cas. Toutes les fibres sauf le WZ ont donné des résistances à l'écrasement suffisantes pour la Classe 150. Le AK, AX et WX ont donné des tuyaux de Classe 200 malgré leur manque de densité.

Les résistances hydrostatiques calculées pour des épaisseurs équivalentes entre 19.7 et 21.2mm furent suffisantes pour les Classes

100 et 150 pour toutes les fibres. Les AK, WX et 4T furent adéquates pour des tuyaux de Classe 200 malgré leur faible densité.

Il est recommandé que la résistance à la déformation plastique soit étudiée en utilisant les mêmes fibres comme une des composantes d'un mélange à tuyau industriel incluant d'autres classes de fibres qui peuvent favoriser la formation de vides avant que le produit atteigne l'accumulateur pour assurer la stabilité dimensionnelle.

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SUMMARY

Phase 1, Part 1:

The following grades of which the WX and WZ are wet milled fibrs that were not fiberized and the others were opened by Willow fiberization were evaluated by the Fibre Strength Unit test. The results obtained were:

AK	109	Fibre Strength Units
WX	101	
4T	86	
WZ	83	
AX	62	

It was concluded that wet milled grades were intermediate in FSU between the AK and AX. Note: AK, 4T and AX were not fiberized to their optimum degree.

Phase 1, Part 2

Flat sheets were produced on the pilot Hatschek machine and cured by autoclaving. The formulations compared were:

GRADE	FIBRE,%	CEMENT, %	SILICA,%
AK	8	55.2	36.8
WX	8	55.2	36.8
4T	10	54	36
WZ	10	54	36
AX	14	51.6	34.4

Runability was excellent in every way for all the fibers. The densities and porosities obtained were:

Grade	DENSITY		POROSITY
	g/cm^3	lb/ft^3	%
WZ	1.54	96	28
WX	1.45	91	30
AX	1.38	86	33
AK	1.34	84	35
4T	1.29	81	39

The wet milled grades were found to be comparatively superior with respect to density and porosity and are therefore expected to yield more durable products.

The flexural strengths when averaged for machine and cross directions, pressed and unpressed gave the following results.

AVERAGE ADJUSTED FLEXURAL MODULI OF RUPTURE

GRADE	MPa	psi
AK	41.8	6060
AX	39.6	5740
WZ	34.7	5080
WX	34.6	5060
4T	34.1	4950

It was concluded that the wet milled fibres were slightly inferior, but quite adequate, in flexural strength. However, when we take into account the fibre ratio used, the wet milled fibres give comparable performance. Refer to Table 8A.

Phase 1, Part 3

Flat sheets were produced on the pilot Hatschek machine and cured in saturated moist air for 28 days. The following formulations were tried:

GRADE	FIBRE, %	CEMENT, %
AK	8	92
WX	8	92
4T	10	90
WZ	10	90
AX	14	86

Runability was excellent in every way for all the fibres. The densities and porosities obtained were:

GRADE	DENSITY		POROSITY
	g/cm³	lb/ft³	%
WZ	1.62	101	24.8
WX	1.58	99	23.7
AX	1.46	91	28.3
AK	1.46	91	29.0
4T	1.41	88	30.6

The air cured products of wet milled grades were found superior in density and porosity.

The flexural strengths averaged for machine and cross directions, pressed and unpressed, gave the following results:

	AVERAGE ADJUSTED FLEXURAL MODULI OF RUPTURE	
GRADE	MPa	psi
AK	43.8	6353
WX	38.8	5626
4T	37.4	5453
AX	36.4	5279
WZ	33.4	4844

However, if we take into account the fibre ratio used to arrive at the reinforcing efficiency the rankings are:

FIBRE EVALUATED	STRENGTH MR_A, MP_a	FIBRE RATIO Qf, %	EFFICIENCY MR_A,/ Qf
AK	43.8	8	5.48
WX	38.8	8	4.85
4T	37.6	10	3.76
WZ	33.4	10	3.34
AX	36.4	14	2.60

The moist air cured flat sheets give results indicating that the wet milled fibres are inferior to the AK but superior to the AX. Results from air cured products are slightly inferior (at 28 days) to those from autoclaved products, but generally similar.

Phase 2, (pipes)

Runability was excellent in every way except for the plastic deformation obtained particularly with the three shorter grades AX, WX and WZ. This is not unexpected since fibre blends including grades that promote resistance to plastic deformation were not used as the furnish (each fibre was tested alone).

The pipe densities obtained, 1.4 to 1.6g/cm^3, were significantly inferior to the densities that might be achieved with a full scale industrial Hatschek machine (1.7 to 1.9g/cm^3) and low density may adversely affect porosity, crushing strength and hydrostatic strength.

Pipe porosities ranging between 23 and 31% were obtained that varied inversely with the densities.

The crushing strengths calculated for thichnesses between 19.7 and 21.2 were sufficient for Class 100 in all cases. All fibres except the WZ gave strengths sufficient for Class 150. The AK, AX and WX yielded Class 200 pipes despite the shortfall in density.

The hydrostatic strengths calculated for thickensses between 19.7 and 21.2mm were sufficient for Classes 100 and 150 for all grades. The AK, WX and 4T were adequate for Class 200 pipes despite the low density.

It is recommended that the resistance to plastic deformation be studied using these grades as one component in an industrial pipe furnish including other grades that can promote the formation of air voids prior to the accumulator roll to ensure green dimensional stability.

HATSCHEK MACHINE TEST COMPARING WET VS DRY MILLED ASBESTOS FIBRES FOR ASBESTOS-CEMENT APPLICATION

INTRODUCTION

At the request of Mr. D. Doyle of CANMET, MSL Division, of the Department of Energy, Mines and Resources of Canada, and with the approval of Ms G. Dagenais, Science Procurement Officer of the Canadian Department of Supplies and Services, Science Branch, a contract for the execution of a Hatschek machine test comparing wet Vs dry milled asbestos fibres for asbestos-cement application was signed on 11 March 1987. The contract was approved on 20 October 1987 by Ms D.G. Dagenais and it was received on 28 October 1987 with an effective commencement date of 20 October 1987.

The project included two phases. Phase 1, covered the Fibre Strength Unit (FSU) evaluation of five fibres and the Hatschek machine production and testing of flat sheets of asbestos-cement cured by both methods saturated moist air or autoclaving. The second phase included the Hatschek machine production of asbestos-cement pipes from the fibres under evaluation, and the physical and mechanical testing of these pipes.

FIBRES EVALUATED

The fibres submitted for evaluation were the following.

GRADE	PRODUCER
AK	Cassiar Mining Corp.
AX	"
WX	"
WZ	"
4T	Québec

The WX and WZ are produced by wet milling and the others are produced by dry milling.

Phase 1, Part 1

Fibre Strength Unit Evaluation

The standard ASTM Method D3880 was used to evaluate the fibre to estimate their reinforcing potential. The standard method was modified with regard to the fiberization of the fibres. The standard calls for 60 min. ball milling followed by two passes in a BOP fiberizer. That technique is adequate to determine the full theoretical reinforcing value of chrysotile asbestos fibres. However, it was desired to compare the fibres on the basis of a less than optimum degree of fiberization to reflect current industrial practice. Accordingly, it was decided to fiberize the dry milled fibres by passing them once through a Willow hammer mill with four rows of hammers, and to test the wet milled fibres as received without any further fiberization. The latest revision of Method D3880 was used that includes loading of the specimens equally and simultaneously at both one-third points of the span (Fig. 1). The following results were obtained:

TABLE 1- Fibre Strength Unit Test Results

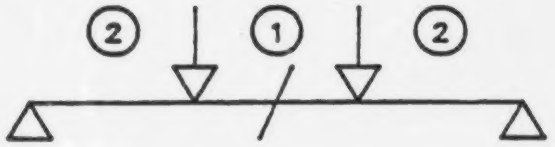
GRADE	FIBRE/DRY SOLIDS RATIO %	ADJUSTED FLEXURAL MODULUS OF RUPTURE (MRa)			FIBRE STRENGTH UNIT units	POINT VALUE points	*VALIDITY OF THE RESULT
		psi	kgf/cm²	MPa			
AK	9	3755	264	25.9	106	70	valid
	9.5	4011	282	27.7	108	70	valid
AX	9.5	4039	284	27.9	109	71	valid
	11.5	3343	235	23.0	76	47	no
	12.5	3456	243	23.8	72	45	no
	13.5	3599	253	24.8	69	42	no
4T	10.5	3655	257	24.7	90	57	no
	11.5	3783	266	26.1	85	54	valid
WX	9.5	3698	260	25.5	100	65	no
	10.5	4238	298	29.2	103	67	no
WZ	11.0	3783	266	26.1	88	56	valid
	12.0	3840	270	26.5	82	52	valid

* Valid results must have an MR_A between 261 and 288 kgf/cm². Refer to Annex 1-1 to 1-11 for complete raw data and calculated results

Figure 1

DETERMINATION DE LA RESISTANCE A LA FLEXION D'UNE EPROUVETTE CHARGEE AUX TIERS.

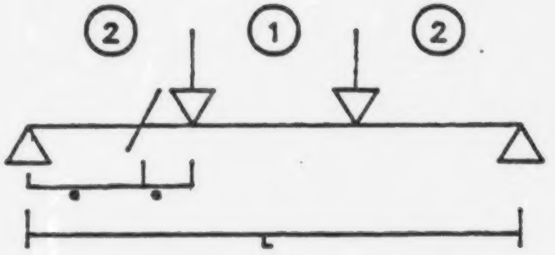
FORMULES :



R = module de rupture (kg)
P = charge maximum (kg)
L = portee (cm)
b = largeur moyenne (cm)
d = epaisseur moyenne (cm)

RUPTURE DANS ZONE 1 :

$$MRt = \frac{PL}{bd^2}$$



a = distance entre la ligne
de rupture et l'appui
le plus proche (cm).

RUPTURE DANS ZONE 2 :
si C/L $\leq$ 5%

$$MRt = \frac{3Pa}{bd^2}$$

$$MRa = \frac{MRt \times 2.56}{(Dt)^2}$$

MPa = 0.0980665 kg/cm2

The above results were obtained by following the standard method of FSU calculation based upon a rejection of any flexural modulus of rupture tested that differs from the average by more than 7.5%. Based upon rigorous statistical concepts we are not justified in rejecting any such outlying results unless it can be demonstrated by Student's test that the outlying results are indeed not a part of the same population of the results obtained on all ten test specimens evaluated per FSU test. In fact, none of the individual results obtained on each specimen tested can pass Student's test. Accordingly, for the purpose of predicting the fibre content required for the Hatschek machine trials, the following FSU results, based upon all ten test specimen results for each trial, were calculated:

Table 2- Fibre Strength Unit Test results based upon the average of all ten test specimens.

GRADE	FIBRE/DRY SOLIDS RATIO USED %	ADJUSTED FLEXURAL MODULI OF RUPTURE (MRA)			FIBRE STRENGTH UNIT units	POINT VALUE POINTS	*VALIDITY OF THE RESULT
		psi	kgf/cm^2	MPa			
AK	9.5	4045	284	27.9	109	71	valid
WX	9.5	3755	264	25.9	101	66	valid
4T	11.5	3840	270	26.5	86	54	valid
WZ	12.0	3873	272	26.7	83	52	valid
AX	16.1	3911	275	27.0	62	37	**graphic extrapolation

* Valid results must have an MR_A between 261 and 288 kgf/cm^2.
** This result was extrapolated from three adjusted flexural moduli of rupture (235, 243 and 253) up to 275 kgf/cm^2 as shown in Fig. 2.

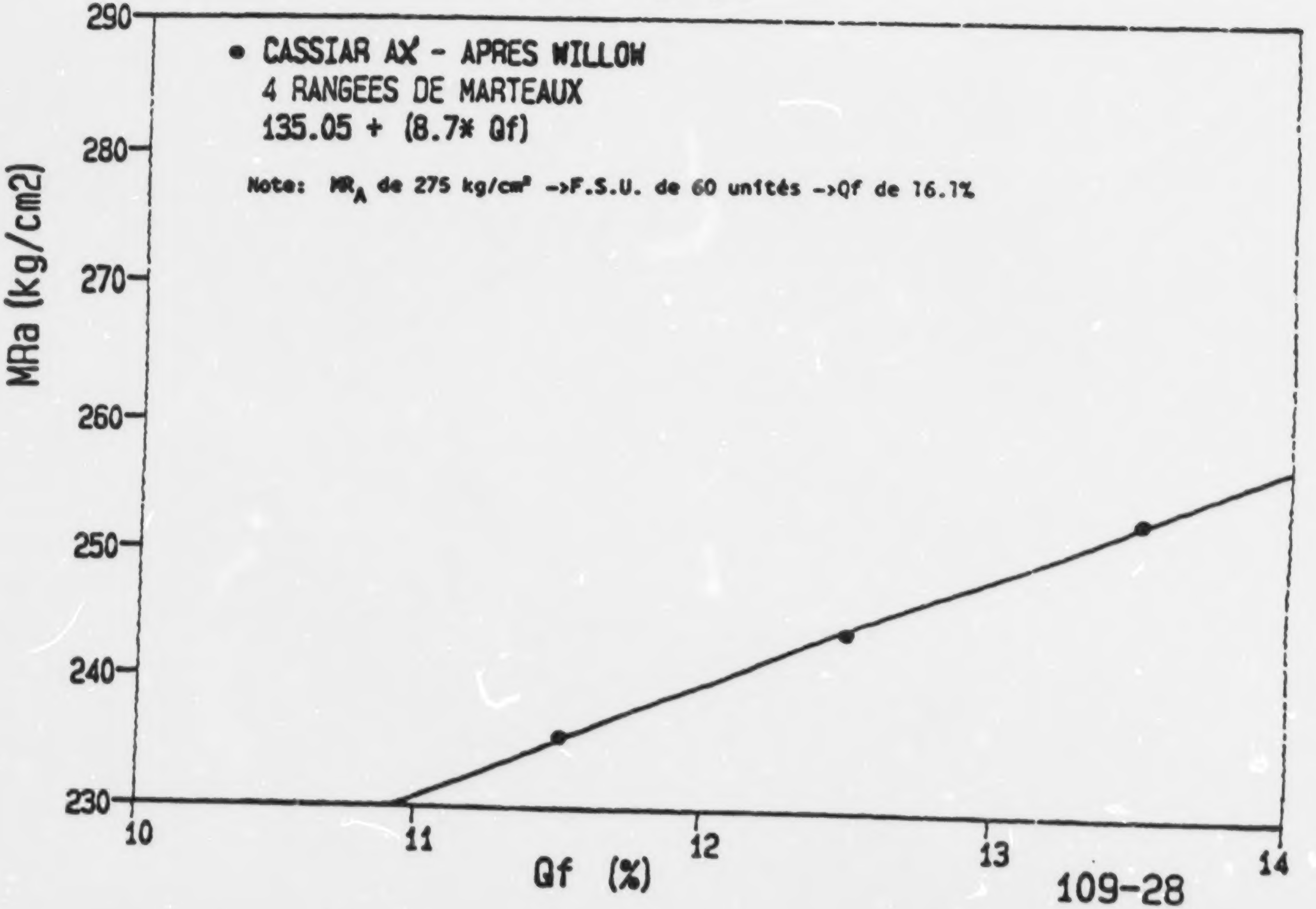
In interpreting the above FSU results, it must be kept in mind that the fibres were not fiberized to the optimum degree.

Phase 1, Part 2

Machine production and testing of autoclaved sheets

The following reinforcing potentials were accordingly theoretically predicted for the Hatschek machine production trials.

FIG.2.- MRa vs Qf



Note: MR_A de 275 kg/cm² ->F.S.U. de 60 unités ->Qf de 16.1%

109-28

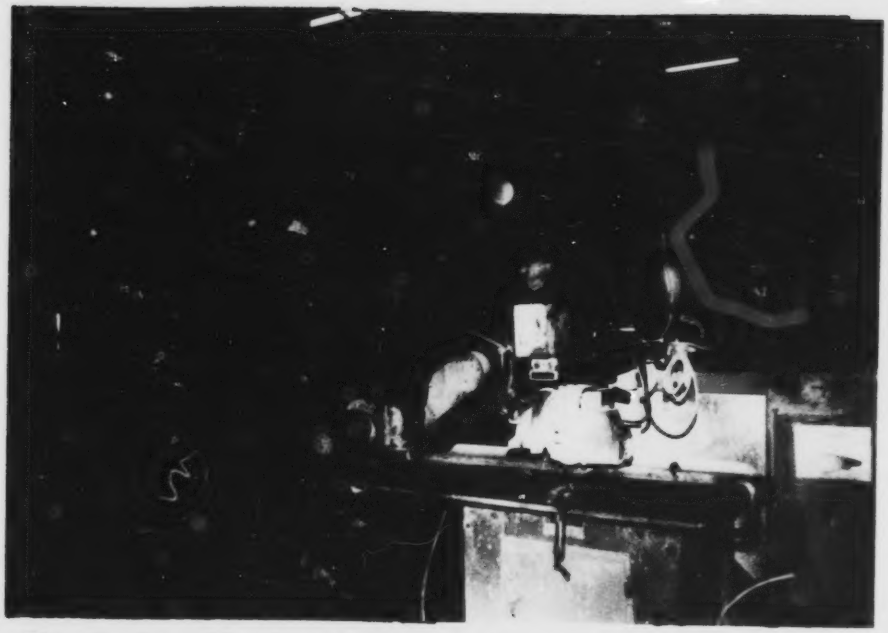


Fig. 3 Overall view of the Hatschek machine pilot plant.

Table 3-- Theoretical fibre/dry solids ratios of Hatschek machine production.

GRADE	FIBRE STRENGTH UNIT units	VALIDITY OF THE FSU RESULTS	FIBRE/DRY SOLIDS RATIO REQUIRED %
AK	107	valid	9.3
WX	101	valid	9.9
4T	86	valid	11.7
WZ	83	valid	12.1
AX	62	*graphic extrapolation	16.1

* This result was extrapolated from three adjusted flexural moduli of rupture (235, 243 and 253) up to 275 kgf/cm² as shown in Fig. 2.

Taking into consideration the requirements of industrial production, based upon our experience, and the theoretical predictions based upon the Fibre Strength Unit test results, the following ratios of fibre-to-dry-solids were adopted for the final production runs:

Table 4-- Actual fibre/dry solids ratios for Hatschek machine production.

GRADE	FIBRE/DRY SOLIDS RATIO, %
AX	14
AK	8
4T	10
WX	8
WZ	10

Production of the autoclaved asbestos-cement sheet samples.

All the autoclaved sheet products were produced on the Hatschek machine using the following formulae:

Table 5-- Formulae for autoclaved sheets

GRADE	FIBRE %	CEMENT %	SILICA %
WX	8	55.2	36.8
WZ	10	54	36
AK	8	55.2	36.8
AX	14	51.6	34.4
4T	10	54	36

Runability was excellent in every case. The following production parameters were observed during the fabrication of the above products:

Table 6-- Runability parameters observed during the production of the autoclaved sheets.

GRADE	4T	AX	AK	WX	WZ
Autoclaved products:					
Product code	386	387	388	389	390
Lamellae/6mm thick	55	48	51	57	67
Feed consistency, g/cm³	91	84	96	79	70
White water solids, g/dm³	29	22	27	15	22

If the number fo lamellae per 6mm of thickness is an indication of drainage speed for a given feed consistency, then as may be observed above, the drainage performance of the wet milled fibres was as good as that of the commercial dry milled comparison fibres.

The retention efficiency is indicated by the white water solids concentration. In every case, the retention efficiency of the wet milled fibres was superior.

The dispersability of the wet milled fibres was observed to be superior to that of the comparison fibres. The WZ fibres were the best in this respect. The AK commercial dry milled fibres were the most resistant to dispersion during the wet mixing operation and this resulted in a product with a splotchy surface covered with the so-called asbestos flowers.

Strength analysis testing of flat sheets.

The strength analysis testing for those flat sheet products that were autoclaved was carried out and the following results were obtained as tested (without density adjustments of the moduli).

Table 7- Test results obtained on autoclaved sheets

GRADE	4T	AK	AX	WX	WZ
Fibre ratio	10	8	14	8	10
Non-pressed products:					
Density, g/cm^3	1.29	1.34	1.38	1.45	1.54
Absorption, %	39	35	33	30	28
Flexural modulus of rupture as tested (MR_T)					
Machine direction, MPa	24.2	32.8	32.0	33.1	31.6
Cross direction, MPa	18.8	23.7	23.8	30.4	24.4
Average(unpressed), MPa	21.5	28.3	27.9	31.8	28.0
Machine direction, psi	3510	4760	4640	4700	4580
Cross direction, psi	2730	3440	3450	4310	3540
Average unpressed, psi	3120	4100	3960	4510	4060

Table 7-Continuation

Pressed products	4T	AK	AX	WX	WZ
Density, g/cm^3	1.51	1.58	1.61	1.65	1.74
Absorption, %	29	25	24	22	21
Flexural modulus of rupture as tested, (MR$_T$)					
Machine direction, MPa	35.8	48.5	48.1	45.2	42.2
Cross direction, MPa	27.2	36.5	35.7	37.0	32.5
Average(pressed), MPa	31.5	42.5	41.9	41.1	37.4
Machine direction, psi	5190	7030	6980	6560	6120
Cross direction, psi	3950	5290	5180	5370	4710
Average pressed, psi	4570	6160	6080	5960	5420
Grand average, MPa	26.5	35.4	34.9	36.4	32.7
Grand average, psi	3840	5130	5060	5280	4740

The following results were obtained for the density-adjusted moduli:

Table 8- Density-adjusted flexural moduli obtained on autoclaved sheets

Unpressed products:	4T	AK	AX	WX	WZ
Machine direction, MPa	37.2	46.5	43.2	36.0	38.6
Cross direction, MPa	29.0	33.6	32.1	33.1	29.8
Average unpressed, MPa	33.1	40.1	37.7	34.5	34.2
Machine direction, psi	5395	6740	6270	5220	5600
Cross direction, psi	4210	4870	4660	4800	4320
Average unpressed, psi	4800	5820	5470	5000	4960
Pressed products:					
Machine direction, MPa	40.0	49.7	47.6	38.0	39.8
Cross direction, MPa	30.3	37.5	35.3	31.2	30.6
Average pressed, MPa	35.2	43.6	41.5	34.6	35.2
Machine direction, psi	5800	7210	5910	5510	5770
Cross direction, psi	4390	5440	4525	4530	4440
Average pressed, psi	5110	6450	5020	5020	5110
Grand average, pressed and unpressed(MR_A)					
MPa	34.1	41.8	39.6	34.6	34.7
psi	4950	6060	5740	5060	5080

Detailed raw data and calculated results are presented in Annex A-1 to A-10.

It was concluded that the wet milled fibres yielded products equivalent to each other and equivalent to those of the 4T fibre; but inferior to the products obtained from the Cassiar AK and AX commercial grades, as far as flexural strength is concerned.

If we take into account the different fibre concentrations required to achieve the above results and refer to the quotients of the flexural moduli of rupture (averaged for orientation and pressing) divided by the percent fibre to dry components ratio, the following efficiency rankings are obtained.

Table 8A-- Efficiency rankings based upon the quotient of the flexural moduli of rupture (averaged for orientation and pressing) divided by the percent fibre to dry components ratio.

GRADE	MODULI MR_A MP_a	FIBRE RATIO %	EFFICIENCY MR_A/Qf
AK	41.8	8	5.23
WX	34.6	8	4.33
WZ	34.7	10	3.47
4T	34.1	10	3.41
AX	39.6	14	2.83

With regard to density, the wet milled fibres yielded results that were equivalent to each other but superior to the three dry milled comparison fibres.

With regard to water absorption or porosity, the wet milled fibres yielded products that were equivalent to each other but superior to those of the three dry milled comparison fibres.

The higher density and lower porosity performance of the wet milled fibres are expected to yield more durable asbestos-cement products that would be more resistant to freezing and thawing and more resistant to aggressive waters or corrosive vapors.

Phase 1, Part 3

Machine production and testing of moist air cured sheets

The saturated moist air cured sheets were produced on the Hatschek machine using the following formulae:

Table 9-- Formulae for saturated moist air cured flat sheets.

GRADE	FIBRE, %	CEMENT, %
WX	8	92
WZ	10	90
AK	8	92
AX	14	86
4T	10	90

Runability was excellent in every case. The following production parameters were observed during the fabrication of the above formulations:

Table 9A-- Runability parameters observed during the production of the saturated moist air cured sheets.

GRADE	4T	AX	AK	WX	WZ
Air cured products:					
Product code	381	382	383	384	385
Lamellae/6mm thick	52	41	54	49	59
Feed consistency,g/dm^3	85	78	75	77	73
White water solids,g/dm^3	27	17	29	14	23

If the number of lamellae per 6mm of thickness is an indication of drainage speed for a given feed consistency, then as may be observed above, the drainage performance of the wet milled fibres was as good as that of the commercial dry milled comparison fibres.

The retention efficiency is indicated by the white water solids concentration. In every case the retention efficiency of the wet milled fibres was superior.

The dispersability of the wet milled fibres was observed to be superior to that of the comparison fibres. The WZ fibres were the best in this respect. The AK commercial dry milled fibres were the most resistant to dispersion during the wet mixing operation and this resulted in a product with a splotchy surface covered with the so-called asbestos flowers.

After curing in saturated moist air at room temperature for 28 days, these sheets were tested and the following results were obtained.

From the grand average results of adjusted flexural modulus of rupture (MR_A) for pressed and unpressed products tested in the machine and cross directions, the following conclusions can be arrived at:

The rankings in flexural strength in decreasing order are given in Table 12 hereunder:

Table 12--Rankings of flexural strength in decreasing order

FIBRE USED	ADJUSTED FLEXURAL MODULUS OF RUPTURE (MR_A)	
	MPa	psi
Cassiar AK	43.8	6350
Cassiar WX	38.8	5630
4T	37.6	5450
Cassiar AX	36.4	5280
Cassiar WZ	33.4	4840

However, if we take into account the fibre ratio used to arrive at the reinforcing efficiency, the rankings in decreasing order of efficiency are as presented in Table 13.

Table 13-- Rankings of the quotient of flexural strength and fibre ratio, in decreasing order of efficiency.

FIBRE EVALUATED	STRENGTH MR_A,MP_a	FIBRE RATIO Qf,%	EFFICIENCY MR_A/Qf
Cassiar AK	43.8	8	5.475
Cassiar WX	38.8	8	4.85
4T	37.6	10	3.76
Cassiar WZ	33.4	10	3.34
Cassiar AX	36.4	14	2.60

TABLE 10- Test flexural modulus of rupture obtained on saturated air cured sheets produced on a pilot scale Hatschek machine

Non-compressed products					
Fibre sample	4T	CASSIAR AK	CASSIAR AX	CASSIAR WZ	CASSIAR WX
Fibre condition	willowed	willowed	willowed	as received	as received
Density, g/cm^3	1.41	1.46	1.46	1.62	1.58
Porosity, %	30.6	29.0	28.3	24.8	23.7
Test flexural modulus of rupture, (MR_T)					
Machine direction					
MPa	33.8	42.7	28.3	37.4	43.1
psi	4902	6193	4105	5424	6251
Cross direction					
MPa	25.7	30.2	26.3	33.3	32.9
psi	3727	4380	3814	4830	4772
Average(non-pressed)					
MPa	29.7	36.4	32.3	35.4	38.0
psi	4308	5279	4685	5134	5511
Compressed products					
Density, g/cm^3	1.65	1.67	1.80	1.87	1.81
Porosity, %	20.6	21.0	17.8	16.6	17.4
Test flexural modulus of rupture (MR_T)					
Machine direction					
MPa	44.8	54.9	48.8	46.9	51.1
psi	6498	7963	7078	6802	7411
Cross direction					
MPa	33.3	40.1	36.3	41.9	48.0
psi	4830	5816	5265	6077	6962
Average (pressed)					
MPa	39.0	47.5	42.6	44.4	49.5
psi	5656	6889	6179	6440	7179
Grand average					
MPa	34.4	42.0	37.5	39.9	43.8
psi	4982	6084	5432	5787	6345

TABLE 1-1- Adjusted flexural modulus of rupture obtained on satured air cured sheets produced on a pilot scale Hatschek machine

Non-compressed products					
Fibre sample	4T	CASSIAR AK	CASSIAR AX	CASSIAR WZ	CASSIAR WX
Fibre condition	willowed	willowed	willowed	as received	as received
Density, g/cm^3	1.41	1.46	1.46	1.62	1.58
Porosity, %	30.6	29.0	28.3	24.8	23.7
Adjusted flexural modulus of rupture, (MP_A)					
Machine direction					
MPa	43.6	51.4	46.2	36.4	44.1
psi	6323	7455	6701	5279	6396
Cross direction					
MPa	33.2	36.3	31.7	32.4	33.6
psi	4815	5265	4598	4699	4873
Average(non-pressed)					
MPa	38.4	43.9	39.0	34.4	38.8
psi	5570	6367	5656	4989	5627
Compressed products					
Density, g/cm^3	1.65	1.67	1.80	1.87	1.81
Porosity, %	20.6	21.0	17.8	16.6	17.4
Adjusted flexural modulus of rupture (MR_A)					
Machine direction					
MPa	42.2	50.3	38.7	34.3	40.0
psi	6192	7295	5613	4975	5802
Cross direction					
MPa	31.4	36.8	28.7	30.7	37.6
psi	4554	5337	4163	4453	5453
Average(pressed)					
MPa	36.8	43.6	33.7	32.5	38.8
psi	5337	6324	4888	4714	5626
Grand average					
MPa	37.4	43.8	36.4	33.4	38.8
psi	5453	6353	5279	4844	5626

It is apparent that the wet milled fibres are inferior in reinforcing efficiency to the AK, but superior to the AX.

From Table 10, the following densities are obtained and these are presented in decreasing order:

Table 14-- Densities of saturated moist air cured sheets, in decreasing order of density

FIBRE EVALUATED	DENSITIES, g/cm³	
	UNPRESSED	PRESSED
Cassiar WZ	1.62	1.87
Cassiar WX	1.58	1.81
Cassiar AX	1.46	1.80
Cassiar AK	1.46	1.67
4T	1.41	1.65

It may be concluded that the wet milled fibres are yielding products that are significantly more dense for both pressed and unpressed products.

From Table 10, the following porosities are obtained and these are presented in increasing order of average porosity, in Table 15 hereunder.

Table 15-- Porosities of saturated moist air cured sheets, in increasing order of porosity.

FIBRE EVALUATED	POROSITIES, %		
	UNPRESSED	PRESSED	AVERAGE
Cassiar WX	23.7	17.4	20.5
Cassiar WZ	24.8	16.6	20.7
Cassiar AX	28.3	17.8	23.1
Cassiar AK	29.0	21.0	25.0
4T	30.6	20.6	25.6

It can be concluded that the wet milled fibers are superior to the dry milled comparison fibers on this basis.

The following annexes present the raw data and calculations for the unpressed products: A-1-1, A-1-3, A-1-5, A-1-7 and A-1-9. The upper half of each table contains the data for products tested in the machine direction whereas the lower half contains data for the cross direction.

The conclusions reached for flat sheets produced by saturated air curing confirmed the conclusions based upon the results with autoclaved flat sheets.

PHASE 2

Production and testing of pipes

All the required pipes were produced on the pilot scale Hatschek machine (Fig. 4 to 7). The formulations produced are presented in Table 16.

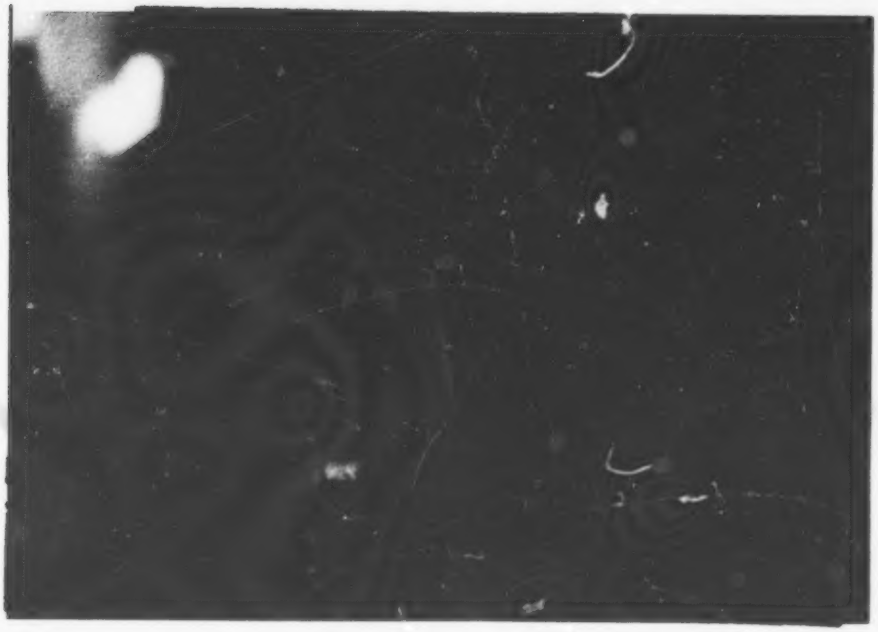


Fig. 4 Asbestos-cement Class 100 pressure pipe production from wet milled chrysotile asbestos on a pilot plant scale Hatschek machine; overhead view from the wet end.

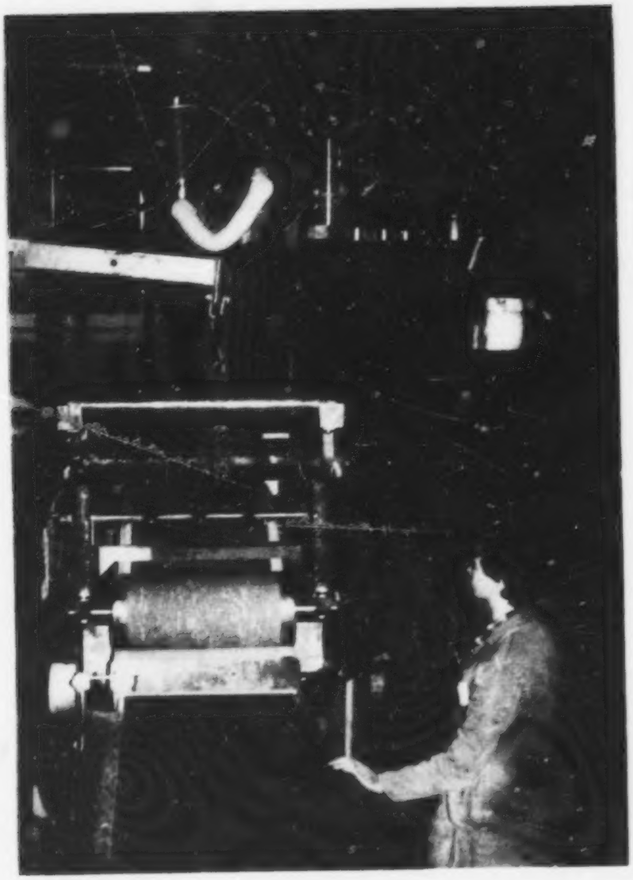


Fig. 4A Asbestos-cement Class 150 pressure pipe-production from wet milled chrysotile asbestos; viewed from the dry end.

Fig. 5 Eight-inch Class 150 asbestos-cement produced from wet milled chrysotile asbestos; on the mandrel at the mandrel removal stage.

FIG. 6

Two 8-in. Class 200 asbestos-cement high pressure pipes produced from wet milled chrysotile asbestos; on mandrels supported by a moist air curing rack.

Fig. 7

Class 100 eight-inch autoclaved asbestos-cement pressure pipes produced from wet milled chrysotile asbestos by the Hatschek process

Table 16-- Formulations used for the pipes.

CODE No.	FIBRE GRADE	FIBERIZATION CARRIED OUT	FIBRE %	CEMENT %	SILICA %
1	4T	1 pass in Willow	12	52.8	35.2
2	4T	1 pass in Willow	12	52.8	35.2
3*	4T	1 pass in Willow	12	52.8	35.2
4	4T	1 pass in Willow	16	50.4	33.6
6**	4T	1 pass in Willow	16	50.4	33.6
7	AX	1 pass in Willow	16	50.4	33.6
8	AX	1 pass in Willow	16	50.4	33.6
9	4T	1 pass in Willow	16	50.4	33.6
10	4T	1 pass in Willow	16	50.4	33.6
11	AK	1 pass in Willow	16	50.4	33.6
12	AK	1 pass in Willow	16	50.4	33.6
13	WX	none	16	50.4	33.6
14	WX	none	16	50.4	33.6
15	WZ	none	16	50.4	33.6
16	WZ	none	16	50.4	33.6

* Pipe No. 3 had lengthwise deformations.

** Pipe No. 5 was defective

The pipe production parameters are presented in Table 17.

Table 17-- Production parameters

CODE No.	FELT SPEED m/min	ROLL PRESSSURE kg/cm	FEED CONSISTENCY g/ℓ	WHITE WATER CONCENTRATION g/ℓ	PIPE THICKNESS mm	NO OF PLIES	*** AVERAGE HARDNESS g	GREEN MOISTURE CONTENT %
1	24	11.5	99.2	23.5	16.6	105	--	--
2	24	11.5	99.2	23.5	16.9	110	--	--
3*	36	11.5	80.6	30.6	15.5	134	36	--
4	13	23	94.9	11.6	15.8	92	43	--
6**	13	23	100.9	11.7	18.8	121	41	--
7	17	23	102.8	14.6	14.5	77	39	--
8	17	23	100.9	19.4	18.3	89	38	12
9	17	23	88.7	11.1	12.7	69	52	9
10	17	23	100.9	19.4	18.3	89	38	9
11	17	23	92.8	16.6	19.0	103	44	11
12	17	23	97.8	17.9	18.8	112	43	10
13	17	23	79.2	7.5	19.2	80	49	9
14	17	23	89.4	10.2	14.1	58	52	6
15	17	23	91.1	8.5	16.8	80	36	10
16	17	23	85.5	10.3	18.4	96	96	37

* Pipe No. 3 had lengthwise deformations.
** Pipe No. 5 was defective (damaged during mandrel removal).
***Durometer scale C.

In every case the dry ingredients were blended for ten minutes prior to wet mixing. Pre-mixing (wet) was next carried out for one minute in the vertical mixer. The 20.3cm(8-in) diameter mandrels were used in each case.

The following curing conditions were used in all cases:

Autoclaving time: 10h
Saturated steam pressure: 0.82MPa
Temperature: 176.7°C

It was intended to produce pipes with wall thicknesses ranging between 19.7 and 21.2mm. However, this was impossible because of the plastic deformation encountered. Commercial pipes are generally produced with a mixture of fibre grades that include one grade that can resist plastic deformation (for example, crocidolite fibres are often used for this purpose).

The fibre grades tested are listed hereunder in Table 18 in decreasing order of resistance to plastic deformation:

Table 18-- Resistance to plastic deformation for each fibre, ranked in decreasing order.

GRADE	SPONTANEOUS MANDREL RELEASE AT	NUMBER OF PLIES OBTAINED			PIPE WALL THICKNESS OBTAINED, mm			HARDNESS DUROMETER SCALE, C	GREEN MOISTURE CONTENT
	nbr. of plies	Min.	Max.	Avg.	Min.	Max.	Avg.	Avg., g	Avg, %
AK	none	103	112	108	19.0	18.8	18.9	43.5	10.5
4T	none	69	138	105	12.6	18.8	16.4	45.0	9
AX	70 to 80	77	89	83	14.5	18.3	16.4	38.5	12
WZ	60 to 70	80	96	88	16.8	18.4	17.6	36.5	8.5
WX	55	58	80	69	14.1	19.2	16.6	50.5	7.5

Strength analysis of the pipes.

Density

Density determinations were carried out in quadruple on all the formulations produced and the results are presented in Table 19.

Table 19-- Density of the pipes produced, in decreasing order of density

CODE No.	FIBRE GRADE	DENSITY, g/cm³			
		MINIMUM	MAXIMUM	AVERAGE	STD. DVN.
7 & 8	AX	1.51	1.62	1.58	0.05
4, 9 & 10	4T	1.44	1.58	1.52	0.05
15 & 16	WZ	1.40	1.55	1.49	0.07
13 & 14	WX	1.41	1.54	1.48	0.06
11 & 12	AK	1.42	1.52	1.467	0.05
Comparison	4T & crocidolite	1.7	1.9	1.8	--

The average densities obtained range between 1.40 and 1.62g/cm³ and these are significantly lower than the densities that might be achieved with a full scale industrial Hatschek machine (1.7 to 1.9 g/cm³) and this limitation must be kept in mind when evaluating the porosity, crushing strength and hydrostatic strength results obtained.

Porosity

Porosity was determined by water absorption measurements in accordance with ASTM Methods C500. The results obtained are presented in Table 20 hereunder.

Table 20-- Porosity of the pipes produced in increasing order of porosity

CODE No.	FIBRE GRADE	POROSITY, %			
		MINIMUM	MAXIMUM	AVERAGE	STD. DVN
7 & 8	AX	22.9	26.3	24.2	1.5
4, 9 & 10	4T	23.6	30.6	26.7	2.8
15 & 16	WZ	25.1	30.4	28.0	2.2
11 & 12	AK	26.2	31.2	28.8	2.6

The fibres evaluated gave porosity rankings identical to their density rankings as should be expected.

Crushing strength

Crushing tests were carried out in accordance with ASTM Standard Methods C500 on pipes produced from each of the fibres under evaluation. See Fig. 8 to 10. The results are presented in Table 21.

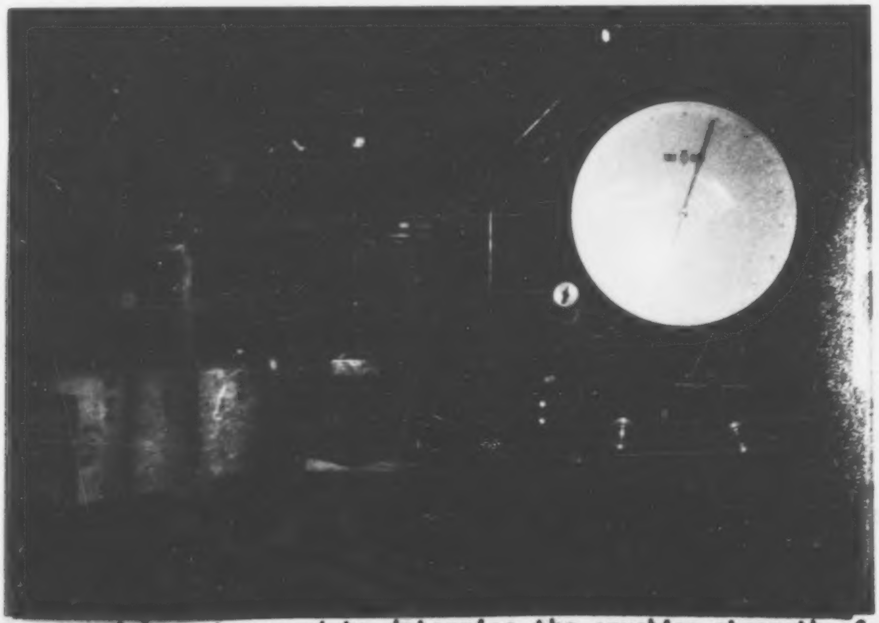


Fig. 8 Press and dynometer used to determine the crushing strength of pipes in accordance with ASTM Method C500. The eight-inch asbestos-cement high pressure Class 200 pipe specimens shown on the left were produced from wet milled chrysotile asbestos.

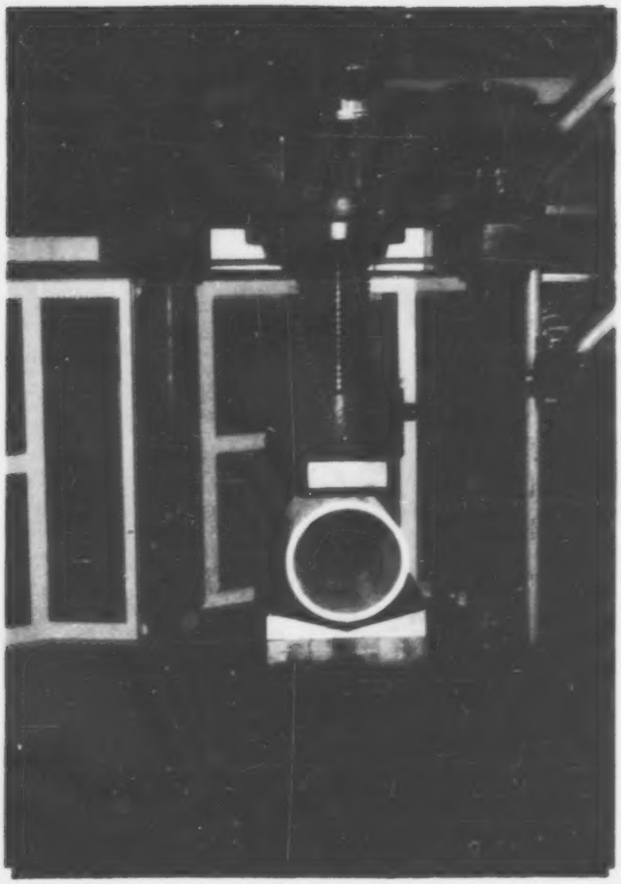


Fig. 9 Class 100 eight-inch asbestos-cement pressure pipe produced from wet milled chrysotile mounted in the press for the determination of crushing strength.

Table 21-- Crushing strength of the pipes produced, in decreasing order of strength.

			CRUSHING STRENGTH, Kn/m			
				CORRECTED FOR THE THICKNESS		
CODE No.	GRADE	AVERAGE THICKNESS mm	AS TESTED	MINIMUM of 19.7mm	MAXIMUM of 21.2mm	AVERAGE of 20.5mm
11	AK	19.5	135	138	159	149
7	AX	14.9	76	133	155	144
14	WX	12.9	57	133	154	144
4 & 9	4T	14.2	60	115	134	125
15	WZ	17.0	51	69	79	74
Comparison	4T and crocidolite	-	-	58	136	80
Class	ASTM C296			100	200	150

All the fibres evaluated gave crushing strengths exceeding the specifications for Class 100 pressure pipe. All fibres except the WZ exceeded the limit for Class 150 even with the minimum thickness of 19.7 mm the following fibres and thickness combinations exceeded the minimum limit for Class 200 pipe:

GRADE	19.7mm	20.5mm	21.2mm
AK	pass	pass	pass
AX	fail	pass	pass
WX	fail	pass	pass

These ratings do not preclude the use of any of the fibres evaluated from reaching the required crushing strength when processed on an industrial scale Hatschek machine to the commercially available densities.

Hydrostatic strength

Hydrostatic tests were carried out in accordance with ASTM Standard Methods C500 on pipes produced from each of the fibres under evaluation. See Fig. 11 to 13. The results are presented in Table 22.

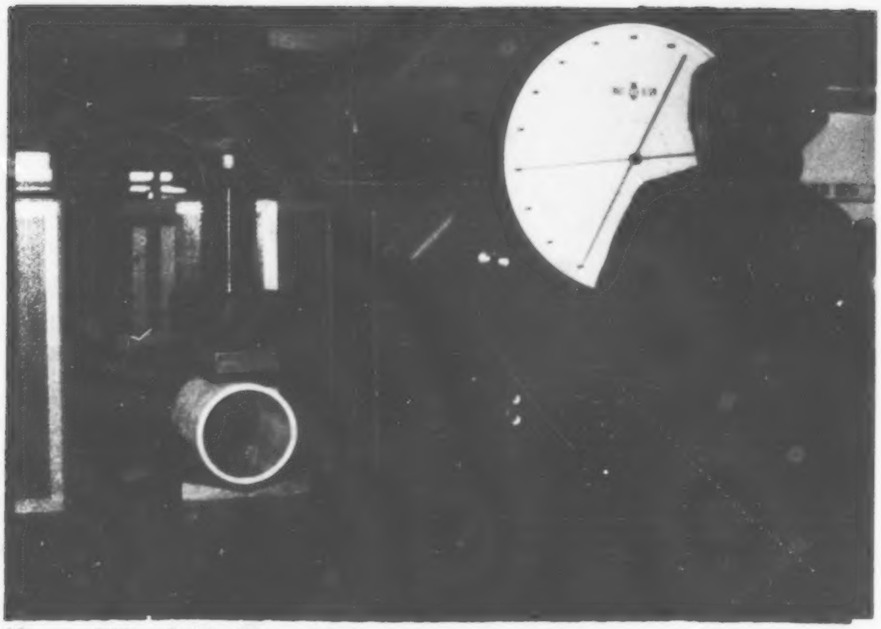


Fig. 10 Class 200 eight-inch high pressure asbestos-cement pipe produced from wet milled chrysotile asbestos undergoing a crushing strength determination in accordance with ASTM Method C500. This specimen eventually broke under a crushing load of 135 kN/m (9246 lbf/linal foot)

Fig. 11 Hydrostatic pressure testing system for testing asbestos-cement pressure pipes in accordance with ASTM Method C500.

Table 22-- Hydrostatic strength of the pipes produced, in decreasing order of strength.

			HYDROSTATIC PROOF PRESSURE, MPa			
				CORRECTED FOR THE THICKNESS		
CODE No.	GRADE	AVERAGE THICKNESS mm	AS TESTED	MINIMUM of 19.7	MAXIMUM of 21.2	AVERAGE of 20.5
12	AK	19.3	4.8	4.8	4.8	4.8
13	WX	18.8	4.8	4.8	4.8	4.8
10	4T	19.5	4.8	4.8	4.8	4.8
8	AX	18.5	4.1	4.4	4.7	4.5
16	WZ	19.0	3.4	3.5	3.8	3.7
Comparison	4T crocidolite	-	-	2.4	4.8	3.6
Class	ASTM C296			100	200	150

All the fibres evaluated gave hydrostatic strengths exceeding the specifications for Class 100 pressure pipe. All the fibres except the WZ exceeded the limit for Class 150 and WZ exceed that limit for pipe wall thicknesses of 19.7 and 20.5mm. The following fibres exceeded the minimum limit for Class 200 pressure pipe for all the pipe wall thichnesses:

AK	passed,
WX	passed and
4T30	passed.

Fig. 12 Class 100 eight-inch asbestos-cement pressure pipe undergoing hydrostatic pressure testing. The pipe specimen which was produced from wet milled chrysotile asbestos is located inside the gray perforated steel cylindrical guard shield at the right.

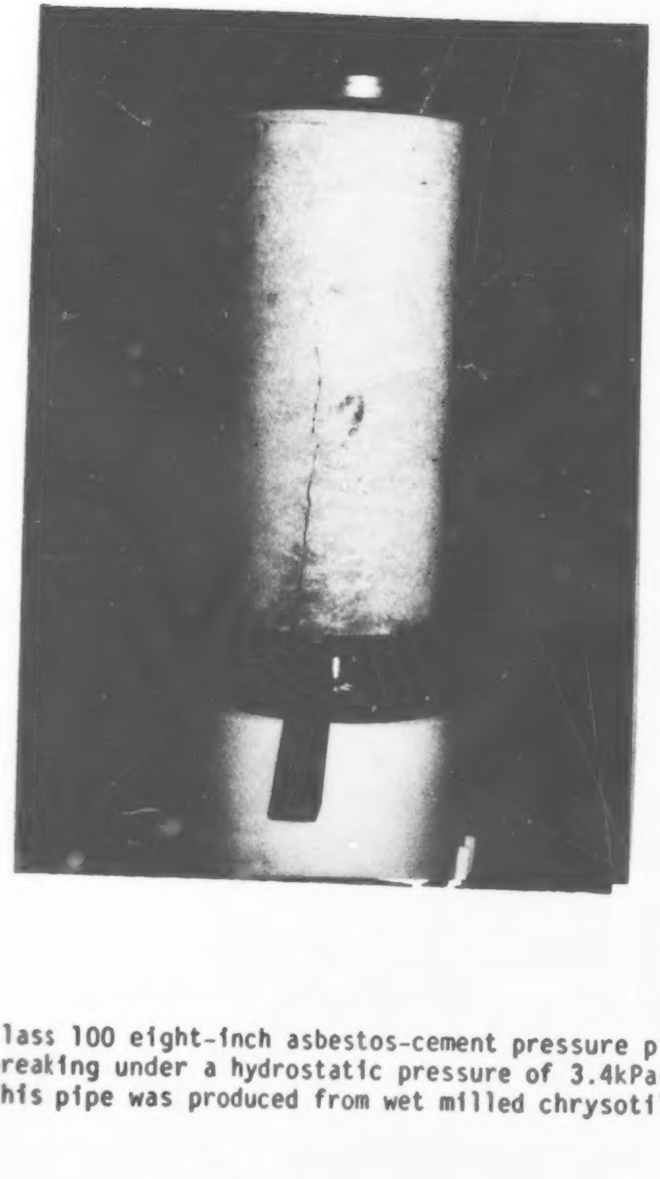


Fig. 13 Class 100 eight-inch asbestos-cement pressure pipe after breaking under a hydrostatic pressure of 3.4kPa(493 psi). This pipe was produced from wet milled chrysotile asbestos.

Conclusions

Phase 1, Part 1 (FSU)

The FSU tests (carried out on dry milled fibre with one pass in a Willow hammer mill, and on wet milled fibres without any fiberization) gave the following results;

Table 23-- FSU rankings

GRADE	FSU
AK	107
WX	101
4T	86
WZ	83
AX	62

leading to the following conclusions:

. the wet milled grades yielded FSU results intermediate between those of the AK and AX.

. the WX is an excellent asbestos-cement grade with an FSU of 101.

Phase 1, Part 2 (autoclaved sheets)

The strength results obtained on flat autoclaved sheets indicate that the fibre ratios for the WX, WZ and 4T were suitable but slightly too high for the AK and significantly too high for the AX. The grand average adjusted flexural moduli of rupture for machine and cross directions, pressed and unpressed, were as follows:

Table 24-- Moduli rankings of sheets

GRADE	GRAND AVERAGE FLEXURAL MODULI OF RUPTURE (MR_A)
AK	41.8MPa
AX	39.6
WZ	34.7
WX	34.6
4T	34.1

If these strength results are divided by the fibre ratio used, in %, the following reinforcement efficiencies are obtained.

Table 25-- Fibre efficiency rankings

GRADE	QUOTIENT OF GRAND AVERAGE FLEXURAL MODULI OF RUPTURE AND % FIBRE RATIO
AK	5.2MPa/%
WX	4.3
WZ	3.5
4T	3.4
AX	2.8

It is noteworthy that the above ranking comes very close to the FSU ranking given in Table 23.

Regarding density and porosity, the wet milled fibres yielded products superior to those obtained from dry milled fibres. Better durability in freezing and aggressive conditions would be expected from the wet milled fibre products.

Phase 1, Part 3(air cured sheets)

The results obtained on flat air cured sheets confirmed the results obtained on the autoclaved sheets in every way. Flexural strength values were lower for the air cured sheets but these continue to increase in strength long after the initial 28 days of curing and they would eventually approach the strength of the autoclaved sheets.

Phase 2 (pipes)

The density of the pipes produced ranged from 1.40 to 1.62g/cm^3 compared against 1.7 to 1.9g/cm^3 for commercial pipes. It would appear reasonable to expect that acceptable densities could be obtained with the fibres evaluated if the following conditions were met:

[a] The higher roll pressures and more efficient water removal suction boxes available on industrial scale Hatschek machines would have to be used.

[b] The fibres would have to be used as part of a fibre mix including other fibres that can promote resistance to plastic deformation (such as crocidolite).

Idential conclusions would also apply to the porosity of the pipes.

Crushing strength corrected for pipe wall thickness indicates that all the fibre evaluated could satisfy the requirement of Class 100 pipes. All fibres except WZ would satisfy the requirements of Class 150 pipes. The AX and WZ would satisfy the requirements of Class 200 for a thickness of 10.5mm and the AK would be adequate for all thicknesses. It is possible that with suitable densities all the fibres would yield even better performances.

Hydrostatic strength corrected for pipe wall thickness indicates that all the fibres evaluated could satisfy the requirements of Class 100 pipes. All fibres except the WZ exceed the limit for Class 150, and the WZ exceeded that limit for a thickness of 19.5mm. The AK, WX and 4T meet the requirements of Class 200. It is possible that with suitable densities all the fibres evaluated would yield even better performances.

The runability of the wet milled fibres was excellent except with regard to plastic deformation. The data reported in Table 18 indicates that the wet milled fibres may be inferior in this respect. However, to reach a more reliable estimate of the performance that could be expected from industrial scale commercial operations the wet milled fibres would have to be evaluated as one component of a typical industrial fibre furnish.

Recommendations

[a] Compare wet milled against dry milled fibres at both of their optimum degrees of fiberization to establish their comparative reinforcing potential.

[b] All fibres were compared in pipes at a 16% fibre content. It would be instructive to see how the fibres compare at other lower and higher fibre concentrations.

[c] Evaluate the fibres as components of a commercial furnish (fibre mix) including fibres that contribute resistance to plastic deformation.

PROJECT EXTENSION

SOMMAIRE

Phase 3, Partie 1 (résistance FSU)

Les résultats suivants furent obtenus pour les évaluations de résistance FSU:

CLASSE	PROJET	DEFIBRAGE	RESISTANCE (FSU), UNITES
AK-100	extension	Willow	112
AK	initial	Willow	108
AX-100	extension	Willow	105
WX	initial	tel quel	101
4T	les deux	Willow	85.5
WZ	initial	tel quel	85.4
AX	initial	Willow	62.0

La relation suivante entre la résistance (FSU) et la moyenne géométrique de longueur est valable sauf pour la fibre AX:

$$\text{FSU} = 23 \ln (\text{moyenne géométrique, } \mu\text{m}) - 51$$

Les classes de fibres produites par voie humide paraissent inférieures au AK-100, AK et AX-100. Cependant, elles sont égales à ou meilleures que les 4T et AX.

Phase 3, Partie 2 (feuilles plates autoclavées). Les résultats suivants furent obtenus:

				Moyenne pour pressée et non pressée		Grande moyenne module de rupture	
Fibre %	Classe	Project	Défibrage	Densité g/cm³	Porosité %	MR_T MPa	MR_A MPa
8	AK	initial	Willow	1.57	25.0	35.4	41.5
	AK-100	exten.	Willow	1.47	30.7	37.6	44.1
	WX	initial	tel quel	1.70	20.6	32.7	34.7
10	WZ	initial	tel quel	1.75	20.7	36.5	34.6
	4T	les deux	Willow	1.53	25.6	26.5	34.2
14	AX	initial	Willow	1.63	20.8	34.9	39.6
	AX	exten.	Willow	1.47	29.4	37.4	43.7
	AX-100	exten.	Willow	1.53	26.7	36.2	39.5
	WX	exten.	tel quel	1.49	28.9	43.9	49.9
	WZ	exten.	tel quel	1.49	28.2	42.0	47.6
16	AX	exten.	Pallmann	1.51	28.6	40.6	44.7
	WX	exten.	Pallmann	1.46	30.1	47.1	55.5
	WX	exten.	turbine	1.49	29.4	46.9	53.1
	WZ	exten.	turbine	1.46	30.2	42.9	50.7
18	AX	exten.	Willow	1.43	31.4	42.4	52.3
	WX	exten.	tel quel	1.46	30.3	41.0	48.3

Les fibres extraites par voie sèche ou humide ont donné des panneaux plats autoclavés de densités et porosités similaires. Les fibres extraites par voie humide telles que reçues ont généralement donné des produits de résistance flexurale supérieure à celle donnée par les fibres extraites par voie sèche et défibré par une passe au défibreur Willow. L´anisotropie des panneaux contenant les fibres extraites par voie humide fut significativement meilleure dans tous les cas. Avec une seule exception, les fibres extraites par voie humide ont donné des efficacités supérieures. Les défibrages au broyeur Pallmann ou à la turbine (en voie humide) ont donné des résultats de résistance flexurale variables, mais ils ont amélioré l´anisotropie. Basé sur une quantité de données assez limitées, il semble que la classe WX donne des résistances optimales avec 16% de fibres alors que le WZ n´a pas encore plafonné à 18% de fibres.

Phase 3, Partie 3 (tuyaux)

Les résultats suivants furent obtenus:

						Par cm d´épaisseur	
Classe	Défibrage	QF Fibre %	Tuyaux No.	Densité g/cm³	Porosité %	Résistance à l´écrasement kN/m.cm	Résistance hydrostatique MPa/cm
AK	Willow	16	11*	1.51	26	69	--
			12*	1.42	31	75	--
			Ref	1.39	31	76	>2.34
AK-100	Willow	16	17	1.39	31	68	>2.20
			18	1.47	29	46	--
			18R	1.47	29	--	1.79

Classe	Défibrage	QF Fibre %	Tuyaux No.	Densité g/cm³	Porosité %	Par cm d'épaisseur: Résistance à l'écrasement kN/m.cm	Par cm d'épaisseur: Résistance hydrostatique MPa/cm
AX	Willow	14	31	1.52	25	62	>2.19
			32	1.49	27	57	--
		16	7*	1.56	25	51	--
			8*	1.60	23	--	2.22
	Pallmann	16	29	1.43	30	43	--
			30	1.52	26	--	2.08
			30R	1.49	28	--	1.99
	Willow	18	33	1.45	28	66	--
			34	1.44	29	59	>2.19
AX-100	Willow	16	19	1.53	26	59	--
			20	1.50	27	--	1.76
WX	tel quel	14	21	1.48	28	41	--
			22	1.49	27	--	0.59
		16	13*	1.49	28	--	>2.55
			14*	1.47	28	44	--
	Pallmann	16	25	1.42	31	--	1.74
			25R	1.43	30	--	1.83
			26	1.38	32	41	--
	turbine tel quel	16	27	1.38	33	--	0.38
			28	1.38	32	34	--
		18	23	1.42	31	36	--
			24	1.41	31	--	1.74
			24R	1.43	30	--	1.97

						Par cm d'épaisseur	
Classe	Défibrage	QF Fibre %	Tuyaux No.	Densité g/cm^3	Porosité %	Résistance à l'écrasement kN/m.cm	Résistance hydrostatique MPa/cm
WZ	tel quel	14	35	1.44	28	51	--
			36	1.47	28	--	1.72
		16	15*	1.47	28	--	--
			16*	1.53	26	--	--
	turbine	16	39	1.35	33	31	--
			40	1.36	34	--	0.47
	tel quel	18	37	1.38	31	--	1.15
			38	1.39	32	50	--
			38R	1.31	35	39	--
4T	Willow	16	4*	1.52	27	--	--
			9*	1.57	24	--	--
			10*	1.47	29	54	>2.46

* Données du projet initial

Un sommaire des meilleurs résultats est présenté à la page suivante.

					Basé sur la résistance à:		
Classe	Défibrage	Fibre ratio %	Tuyaux No.	Epaisseur cm	Résistance classe	Résistance classe	Ensemble classe
AK	Willow	16	12*	1.93	200	200	200
AK-100	Willow	16	17	2.18	200	200	200
AX	Willow	14	31	2.19	150	200	150
		18	33	2.24	200	--	
AX-100	Willow	16	19	1.62	150	--	150
			20	2.38	--	150	
WX	as received	16	13*	1.88	--	200	150
			14*	1.29	150	--	
WZ	as received	14	35	2.40	150	--	150
			36	1.63		150	
4T	Willow	16	10*	1.95	150	200	150

* Données du projet initial

Pour chaque niveau de teneur en fibres, les fibres extraites par voie humide ont donné des tuyaux dont les résistances à l'écrasement et à la pression hydrostatique sont inférieures. Cependant, il faut tenir compte que les fibres de comparaison sont parmi les meilleures et les fibres extraites par voie humide ont tout de même donné des tuyaux de classe 150 malgré leur manque de densité.

Les difficultés de mise en oeuvre associés aux fibres extraites par voie humide indiquent que ces dernières ne doivent pas être utilisées comme 100% de la fourniture en fibres. Elles doivent être utilisées comme seulement une partie d'un mélange de fibres contenant des fibres rugueuses qui peuvent améliorer la mise en oeuvre.

RECOMMENDATION

Il est recommandé d'évaluer les fibres extraites par voie humide en les utilisant comme une composante d'une fourniture (mélange de fibres) commerciale incluant des fibres qui peuvent contribuer une résistance à la déformation plastique.

PROJECT EXTENSION

SUMMARY

Phase 3, Part 1 (FSU)

The following results were obtained for the fibre strength unit evaluations:

GRADE	PROJECT	FIBERIZATION	FIBRE STRENGTH UNIT, UNITS
AK-100	extension	Willow	112
AK	initial	Willow	108
AX-100	extension	Willow	105
WX	initial	as received	101
4T	both	Willow	85.5
WZ	initial	as received	85.4
AX	initial	Willow	62.0

The following relationship between FSU and geometric mean fibre length holds except for the AX fibre:

$$FSU- 23 \ln (\text{geometric mean}, \mu m) -51$$

The wet milled grades appear inferior to the AK-100, AK and AX-100. However, they are equal to or better than the 4T and the AX.

Phase 3, Part 2 (autoclaved flat sheets)

The following results were obtained:

				Average for pressed and non pressed		Grand average moduli of rupture	
Fibre %	Grade	Project	Fiber- ization	Density g/cm^3	Porosity %	MR_T MPa	MR_A MPa
8	AK	initial	Willow	1.57	25.0	35.4	41.5
	AK-100	exten.	Willow	1.47	30.7	37.6	44.1
	WX	initial	as received	1.70	20.6	32.7	34.7
10	WZ	initial	as received	1.75	20.7	36.5	34.6
	4T	both	Willow	1.53	25.6	26.5	34.2
14	AX	initial	Willow	1.63	20.8	34.9	39.6
	AX	exten.	Willow	1.47	29.4	37.4	43.7
	AX-100	exten.	Willow	1.53	26.7	36.2	39.5
	WX	exten.	as received	1.49	28.9	43.9	49.9
	WZ	exten.	as received	1.49	28.2	42.0	47.6
16	AX	exten.	Pallmann	1.51	28.6	40.6	44.7
	WX	exten.	Pallmann	1.46	30.1	47.1	55.5
	WX	exten.	turbine	1.49	29.4	46.9	53.1
	WZ	exten.	turbine	1.46	30.2	42.9	50.7
18	AX	exten.	Willow	1.43	31.4	42.4	52.3
	WX	exten.	as received	1.46	30.3	41.0	48.3

When compared against the dry milled fibres, the wet milled fibres gave comparable densities and porosities. The wet milled fibres as received yielded generally superior flexural strengths than dry milled fibres opened by one pass in a Willow. The anisotropy of sheets produced with wet milled fibre was significantly better in all cases. With one exception, the wet milled fibres yielded superior fibre efficiencies. Pallmann and wet turbine fiberization of the wet milled grades gave mixed flexural strength results but improved the anisotropy. Based upon limited data it appears that the WX yields optimum strength at 16% fibre while the WZ has not yet peaked at 18% fibre.

Phase 3, Part 3 (pipes)

The following results were obtained:

						Per cm of thickness	
Grade	Fiberization	QF Fibre %	Pipe No.	Density g/cm^3	Porosity %	Crushing strength kN/m.cm	Hydrostatic strength MPa/cm
AK	Willow	16	11*	1.51	26	69	—
			12*	1.42	31	75	--
			Ref	1.39	31	76	>2.34
AK-100	Willow	16	17	1.39	31	68	>2.20
			18	1.47	29	46	--
			18R	1.47	29	--	1.79
AX	Willow	14	31	1.52	25	62	>2.19
			32	1.49	27	57	--
		16	7*	1.56	25	51	--
			8*	1.60	23	--	2.22

						Per cm of thickness	
Grade	Fiber-rization	QF Fibre %	Pipe No.	Den-sity g/cm^3	Poro-sity %	Crushing strength kN/m.cm	Hydrostatic strength MPa/cm
	Pallmann	16	29	1.43	30	43	--
			30	1.52	26	--	2.08
			30R	1.49	28	-	1.99
	Willow	18	33	1.45	28	6	--
			34	1.44	29		>2.19
AX-100	Willow	16	19	1.53	26	59	--
			20	1.50	27	-	1.76
WX	as received	14	21	1.48	28	41	--
			22	1.49	27	--	0.59
		16	13*	1.49	28	--	>2.55
			14*	1.47	28	44	--
	Pallmann	16	25	1.42	31	--	1.74
			25R	1.43	30	--	1.83
			26	1.38	32	41	--
	turbine	16	27	1.38	33	--	0.38
	as received		28	1.38	32	34	--
		18	23	1.42	31	36	--
			24	1.41	31	--	1.74
			24R	1.43	30	--	1.97
WZ	as received	14	35	1.44	28	51	--
			36	1.47	28	--	1.72
		16	15*	1.47	28	--	--
			16*	1.53	26	--	--
	turbine	16	39	1.35	33	31	--
			40	1.36	34	--	0.47

Grade	Fiber-rization	QF Fibre %	Pipe No.	Density g/cm^3	Porosity %	Per cm of thickness: Crushing strength kN/m.cm	Per cm of thickness: Hydrostatic strength MPa/cm
	as received	18	37	1.38	31	--	1.15
			38	1.39	32	50	--
			38R	1.31	35	39	--
4T	Willow	16	4*	1.52	27	--	--
			9*	1.57	24	--	--
			10*	1.47	29	54	>2.46

* Data from the initial project.

The best results are summarized hereunder:

Grade	Fiberization	Fibre ratio %	Pipe No.	Thickness cm	Based on resistance to: Crushing class	Based on resistance to: Hydrostatic class	Overall class
AK	Willow	16	12*	1.93	200	200	200
AK-100	Willow	16	17	2.18	200	200	200
AX	Willow	14	31	2.19	150	200	150
		18	33	2.24	200	--	
AX-100	Willow	16	19	1.62	150	--	150
			20	2.38	--	150	
WX	as received	16	13*	1.88	--	200	150
			14*	1.29	150	--	
WZ	as received	14	35	2.40	150	--	150
			36	1.63	--	150	
4T	Willow	16	10*	1.95	150	200	150

* Data from initial project.

At each fibre ratio level the wet milled fibres gave inferior crushing and bursting strengths. However, it must be kept in mind that the comparison fibres are among the best and the wet milled fibres were able to yield class 150 pipes despite low density.

The poor runability experienced with the wet milled fibres indicates that these may not be used as 100% of the fibre furnish but must be used as part of a fibre mix including harsh fibre to improve runability.

RECOMMENDATION

Evaluate the wet milled fibres as components of a commercial furnish (fibre mix) including fibres that contribute resistance to plastic deformation.

INTRODUCTION

At the request of Mr. D. Doyle of CANMET, MSL Division, of the Department of Energy, Mines and Resources of Canada, and with the approval of Ms. A. Humphries, Science Procurement Officer of the Canadian Department of Supplies and Services, Science Branch, a contract extension for the execution of a Hatschek machine test comparing wet Vs dry milled asbestos fibres for asbestos-cement application was signed on 3 March '88. The contract was approved on 16 June 1988 by Ms. A. Humphries and it was received on 4 July 1988 with an effective commencement date of 22 March 1988.

This project extension, identified as Phase 3, included three parts. Part 1 covered the Fibre Strength Unit (FSU) evaluation of two grades. Part 2 concerned the production and testing of flat autoclaved asbestos-cement sheets produced on a pilot Hatschek machine using five grades and 11 formulations. Part 3 included the production and testing of asbestos-cement pipes produced on a pilot Hatschek machine using five fibres and 12 formulations.

FIBRE EVALUATED

The fibres submitted for evaluation were the following:

PART	EVALUATION	GRADE	FIBRE, %	FIBERIZATION
1	Fibre Strength Unit	AK-100	9	Willow
	Fibre Strength Unit	AX-100	10	Willow
2	Flat autoclaved sheets	AK-100	8	Willow
		AX-100	14	Willow
		AX	16	Pallmann
		AX	18	Willow

PART	EVALUATION	GRADE	FIBRE, %	FIBERIZATION
		WX	14	as received
		WX	16	Pallmann
		WX	16	turbine
		WX	18	Willow
3	Pipes	AK-100	16	Willow
		AX-100	16	Willow
		AX	14	Willow
		AX	16	Pallmann
		AX	18	Willow
		WX	14	as received
		WX	16	Pallmann
		WX	16	turbine
		WX	18	as received
		WZ	14	as received
		WZ	16	turbine
		WZ	18	as received

The AK-100, AX-100 and AX are commercially available grades produced industrially by the traditional dry process. The WX and WZ are experimental wet milled grades produced in a pilot plant with limited availability.

WET MILLED FIBRE HOMOGENEITY

It was observed that the wet milled fibres of WX and WZ did not appear to have a homogeneous distribution of fibre length within each filter cake received, and appeared to vary in length between cakes. Accordingly, these fibres were sampled systematically and analyzed for fibre length distribution by the technique of the McNett wet classification in accordance with ASTM Standard Method D2589. The results are presented in Table 1 for the WX and in Table 2 for grade WZ.

ANALYSIS OF THE VARIANCE IN LENGTH OF WET MILLED FIBRES:

Statistical analysis of the results indicates that the length variations within each filter cake (each bag) are highly significant. The differences in geometric mean lengths between filter cakes (between bags) is not negligeable. Accordingly, it was concluded that these fibres would have to be homogenized before their evaluation could be undertaken.

PROCESS FOR HOMOGENIZATION OF WET MILLED FIBRES:

The homogenization was carried out by dispersing in water aliquots from each filter cake of a given grade and blending them by low speed agitation. The resulting homogeneous slurries were dewatered on a dewatering drum to form filter cakes with masses between 5 and 7kg each of fibre on the dry basis. After dispersal samples of the slurries were taken, and samples of the corresponding resulting filter cakes were also taken for fibre length distribution determinations. The results of these determinations show that fibres with homogeneous fibre length distributions were produced in the dispersed slurries and the corresponding homogenized filter cakes as shown in Table 3 for the WX and Table 4 for the WZ. No significant change in average fibre length could be observed. The mass of dry fibre contained in each homogenized filter cake was determined and the results are presented in Table 5. The fibre length distributions of the homogenized filter cakes was determined and the variations between cakes was no longer significant as shown in Table 6 for the WX and Table 7 for the WZ fibre.

Table 1-- Fibre length distribution by McNett wet classification for grade WX as received.

Lot No.	Bag No.	McNett, % retained on mesh						Geometric mean length mm
		+4M	-4 +16	-16 +40	-40 +100	-100 +200	-200	
1	1	3.3	10.7	29.3	43.3	6.4	7.0	0.634
1	1	3.5	11.2	26.4	43.4	5.9	9.6	0.597
1	1	2.7	9.9	25.1	41.1	5.6	15.6	0.496
1	2	2.8	9.3	24.8	39.1	6.6	17.4	0.471
1	3	3.1	10.1	25.6	40.5	5.9	14.8	0.513
$\bar{X}$		3.1	10.2	26.2	41.5	6.1	12.8	0.542
S		0.3	0.7	1.8	1.8	0.4	4.3	0.069
2	1	11.6	16.2	24.9	34.2	5.6	7.5	0.883
2	1	11.8	14.8	25.5	36.6	5.7	5.6	0.898
2	2	4.3	15.9	30.3	36.1	6.3	7.1	0.745
2	3	4.7	15.7	33.7	35.1	2.7	8.1	0.788
2	4	5.2	17.5	33.7	35.0	4.4	4.2	0.888
2	4	8.7	19.0	30.5	28.1	4.3	9.4	0.891
2	5	5.9	15.7	28.9	33.6	5.7	10.2	0.724
2	6	2.7	12.2	22.9	28.9	4.7	28.6	0.396
2	6	3.1	13.1	25.5	33.6	5.7	19.0	0.506
2	6	4.3	16.7	35.7	33.5	3.0	6.8	0.832
2	7	2.0	11.9	18.4	26.3	7.0	34.4	0.319
2	7	0.9	10.7	21.1	32.8	8.2	26.3	0.360
2	7	3.4	12.4	23.4	35.9	8.7	16.2	0.506
2	8	4.4	16.1	35.2	33.8	2.8	7.7	0.806
$\bar{X}$		5.2	14.8	27.8	33.1	5.3	13.6	0.681
S		3.3	2.4	5.5	3.1	1.8	9.7	0.216

Table 2-- Fibre length distribution by McNett wet classification for grade WZ as received.

		McNett, % retained on mesh						Geometric
Lot No.	Bag No.	+4M	-4 +16	-16 +40	-40 +100	-100 +200	-200 M	mean length mm
1	1	0.7	4.0	22.7	48.1	6.5	18.0	0.375
1	1	0.2	4.5	22.1	48.5	6.7	18.0	0.370
1	1	0.3	4.2	22.2	49.9	6.2	17.2	0.377
1	2	0.8	2.9	11.0	43.5	13.3	28.5	0.246
1	3	0.5	3.0	10.8	43.9	12.6	29.2	0.242
$\bar{X}$								0.322
S								0.071
2	1	0.2	4.2	21.6	50.9	5.8	17.3	0.374
2	2	0.5	4.2	21.3	47.6	6.5	19.9	0.354
$\bar{X}$								0.364
S								0.014

TABLE 3 - FIBRE LENGTH DISTRIBUTION BY McNETT WET CLASSIFICATION FOR GRADE WX; IN THE DISPERSED SLURRIES AND HOMOGENIZED FILTER CAKES

McNETT, % RETAINED ON MESH
U.S. SCREENS

SAMPLE	+4M	-4M +16M	-16M 40M	-40M 100M	-100M 200M	-200M	GEOMETRIC MEAN (mm)
SLURRY SAMPLES							
ECH.#1-1	2.2	9.0	25.8	38.9	5.4	18.7	0.453
#1-2	2.7	9.2	25.0	39.0	6.0	18.1	0.462
ECH.#2-1	2.3	9.3	27.0	40.2	5.9	15.3	0.495
#2-2	2.2	9.0	25.8	38.8	6.0	18.2	0.456
$\bar{x}$	2.35	9.13	25.90	39.23	5.83	17.58	0.466
s	0.24	0.15	0.82	0.66	0.29	1.54	0.019
HOMOGENIZED FILTER CAKES							
ECH.#1-1	2.4	8.8	18.6	45.4	4.4	20.4	0.411
#1-2	1.9	9.4	24.4	41.2	4.9	18.2	0.454
ECH.#2-1	2.3	8.7	24.3	38.3	5.9	20.5	0.427
#2-2	2.0	9.2	25.4	40.2	6.2	17.0	0.463
$\bar{x}$	2.15	9.03	23.18	41.28	5.35	19.03	0.439
s	0.24	0.33	3.09	3.00	0.84	1.72	0.024

TABLE 4 - FIBRE LENGTH DISTRIBUTION BY McNETT WET CLASSIFICATION FOR GRADE WZ; IN THE DISPERSED SLURRIES AND HOMOGENIZED FILTER CAKES

McNETT, % RETAINED ON MESH

SAMPLE	+4M	-4M +16M	-16M 40M	-40M 100M	-100M 200M	-200M	GEOMETRIC MEAN (mm)
SLURRY SAMPLES							
ECH. #1	0.3	3.8	16.8	46.0	8.9	24.2	0.299
ECH. #2	0.3	3.4	18.2	44.6	8.1	25.4	0.296
ECH. #3	0.5	5.8	22.7	38.2	9.0	23.8	0.337
ECH. #4	0.6	6.4	25.3	37.0	7.4	23.9	0.355
$\bar{x}$	0.43	4.85	20.75	41.45	8.35	24.33	0.322
s	0.15	1.47	3.94	4.51	0.75	0.74	0.029
HOMOGENIZED FILTER CAKES							
ECH. #1	0.3	3.7	19.7	46.7	8.5	21.1	0.329
ECH. #2	0.3	3.1	19.7	47.6	9.0	20.3	0.328
ECH. #3	0.6	5.4	25.6	37.1	9.0	22.3	0.356
ECH. #4	0.7	6.6	24.1	38.7	7.9	22.0	0.368
$\bar{x}$	0.48	4.70	22.28	42.53	8.60	21.43	0.345
s	0.21	1.60	3.04	5.39	0.52	0.91	0.020

TABLE 5. DRY MASS OF HOMOGENISED FILTER CAKES

SAMPLE No	MOIST MASS (kg)	MOISTURE CONTENT				DRY MASS (kg)
		TRIAL 1 (%)	TRIAL 2 (%)	TRIAL 3 (%)	AVERAGE (%)	
FIBRE WX						
H1	9.78	53.25	51.10		52.18	4.677
H2	12.44	46.50	46.65		46.58	6.646
H3	11.28	54.30	52.35	53.25	53.30	5.268
H4	16.06	59.05	52.45	57.35	56.28	7.021
H5	14.64	56.40	55.65	56.15	56.07	6.432
H6	13.01	53.55	57.35	55.60	55.50	5.789
H7	12.66	54.25	55.90	55.85	55.33	5.655
H8	14.15	55.95	53.45	54.95	54.78	6.398
H9	12.83	54.35	52.75	54.75	53.95	5.908
H10	15.34	55.75	53.95	54.65	54.78	6.936
H11	15.52	55.40	53.35	54.90	54.55	7.054
H12	14.45	56.00	52.70	54.80	54.50	6.575
H13	15.60	55.75	54.25	54.80	54.93	7.030
H14	12.40	56.30	52.25	53.85	54.13	5.687
TOTAL	190.16			$\bar{X}$ =	54.06	87.077
FIBRE WZ						
H15	12.68	55.80	55.00	54.55	55.12	5.691
H16	9.82	48.95	52.25	49.15	50.12	4.899
H17	12.40	53.90	55.65	54.15	54.57	5.634
H18	12.36	55.35	54.70	54.90	54.98	5.564
H19	15.06	54.45	59.60	52.75	55.60	6.687
H20	7.50	55.50	52.75	51.75	53.33	3.500
H21	2.96	44.82	40.52	47.58	44.31	1.649
H22	11.20	50.67	47.09	52.65	50.14	5.585
H23	6.12	45.40	43.93	43.28	44.20	3.415
H24	10.46	46.66	46.08	42.97	45.24	5.728
H25	6.47	43.98	42.46	41.16	42.53	3.718
H26	9.55	44.36	43.28	42.94	43.53	5.393
TOTAL	116.58			$\bar{X}$ =	49.47	57.462

TABLE 6

McNETT FIBRE LENGTH DISTRIBUTION OF WX HOMOGENIZED FILTER CAKES

HOMOGENIZED FILTER CAKE	McNETT, % RETAINED ON MESH						GEOMETRIC MEAN (mm)
	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	
H1	2.1	9.1	21.5	43.3	4.7	19.3	0.431
H2	2.1	9.0	24.9	39.2	6.1	18.7	0.445
H3	2.9	13.2	28.2	36.6	5.7	13.4	0.582
H4	3.8	14.0	29.0	34.7	5.0	13.5	0.617
H5	4.4	14.3	30.4	34.7	5.8	10.4	0.678
H6	4.4	13.6	30.7	33.7	5.2	12.4	0.646
H7	3.3	14.2	30.4	35.5	5.5	11.1	0.647
H8	4.1	14.2	30.8	34.7	5.9	10.3	0.674
H9	4.7	13.9	28.9	33.2	4.1	15.2	0.615
H10	4.2	12.8	31.3	33.5	5.7	12.5	0.630
H11	2.7	13.9	28.3	35.1	5.5	14.5	0.576
H12	3.4	12.8	29.7	34.7	5.2	14.2	0.587
H13	6.5	16.1	29.4	32.3	4.0	11.7	0.739
H14	4.4	15.2	29.2	35.3	5.1	10.8	0.683
$\bar{X}$	3.79	13.31	28.76	35.46	5.25	13.43	0.611
s	1.16	2.00	2.62	2.79	0.64	2.82	0.086

NOTE: H1 AND H2 COME FROM LOT #1 BAGS 1 AND 2.
H3 TO H14 COME FROM LOT #1 BAG 3 AND LOT #2 BAGS 1 TO 8.

TABLE 7

McNETT FIBRE LENGTH DISTRIBUTION OF WZ HOMOGENIZED FILTER CAKES

HOMOGENIZED FILTER CAKE	McNETT, % RETAINED ON MESH						GEOMETRIC MEAN (mm)
	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	
H15	0.3	3.4	19.7	47.1	8.8	20.7	0.328
H16	0.2	3.4	19.7	47.9	9.9	18.9	0.336
H17	0.3	3.5	18.7	46.9	8.6	22.0	0.318
H18	0.3	3.5	18.2	44.9	10.0	23.1	0.305
H19	0.3	3.9	17.7	44.0	9.0	25.1	0.297
H20	0.6	4.0	18.1	47.3	10.1	19.9	0.332
H21	0.6	6.1	25.6	38.8	8.5	20.4	0.378
H22	0.6	5.4	25.6	37.1	9.0	22.3	0.356
H23	0.6	5.7	23.1	38.7	8.0	23.9	0.342
H24	0.5	6.3	25.4	35.6	8.0	24.2	0.351
H25	0.7	6.6	24.1	38.7	7.9	22.0	0.368
H26	0.5	6.8	26.5	38.5	6.2	21.5	0.386
$\bar{x}$	0.46	4.88	21.87	42.13	8.67	22.00	0.341
s	0.17	1.38	3.47	4.62	1.09	1.86	0.028

NOTE: H15 TO H20 COME FROM A BLEND OF LOT #1
H21 TO H26 COME FROM FROM A BLEND OF LOT#2

FIBERIZATION

WILLOW FIBERIZATION:

The dry milled fibres AK-100, AX-100 and AX were fiberized by one pass in a Willow hammer mill equipped with four rows of hammers, at 1770 r/min (185rad/s). Each row was fitted with six hammers. The degree of fiberization was determined before and after passage in the Willow by air permeability measurements in accordance with ASTM Methods D2752. The following results were obtained:

FIBRE GRADE	RAPID SURFACE AREA BY AIR PERMEABILITY BEFORE WILLOW, dm^2/g	AFTER WILLOW, dm^2/g
AK-100	107.9	170.0
AX-100	101.2	153.4
AX	45.1	111.8

PALLMANN FIBERIZATION:

The AX and WZ were opened in the Pallmann fiberizer. The WZ fibre was first dried approximately 66h in an oven at 110°C. The fibres were passed once through the Pallmann fiberizer without any retention ring at a speed of 6500 r/min (681 rad/s). The degree of fiberization achieved was determined by air permeability and the following results were obtained:

FIBRE GRADE	RAPID SURFACE AREA BY AIR PERMEABILITY dm^2/g
AX	>260
WX	233.6

The reduction in fibre length caused by the Pallmann fiberization was determined by means of the McNett wet classification. The results are presented in Table 8 for the AX and Table 9 for the WX fibre. The reductions in geometric mean length caused by Pallmann fiberization were as follows:

GRADE	REDUCTION IN GEOMETRIC MEAN LENGTH
AX	70%
WX	32%

WET FIBERIZING (TURBINE):

Wet fiberizing was carried out by means of a turbine impeller operating at 3450 r/min (361 rad/s) using a 2.5% aqueous slurry for 30 min. The reduction in fibre length and increase in length homogeniety caused by the wet fiberizing was determined by carrying out McNett wet classifications on nine separate batches before and after processing with the turbine. The results obtained are presented in Table 10 for the WX and Table 11 for the WZ fibre. The results indicate the following decreases in average geometric mean length and dispersion of data expressed as a reduction in standard deviations:

GRADE	REDUCTION IN AVERAGE GEOMETRIC MEAN LENGTH	REDUCTION IN STANDARD DEVIATION
WX	34%	70%
WZ	30%	76%

COMPARATIVE PROPERTIES OF THE FIBRES:

In order to compare the fibres received for the project extension

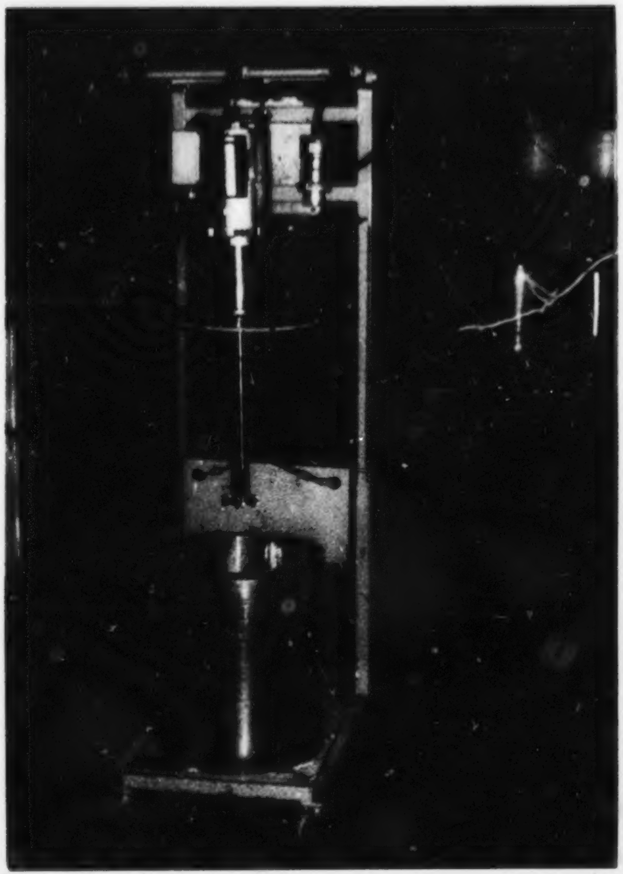


Fig. 13.1 Wet turbine fiberizer shown in the open position.

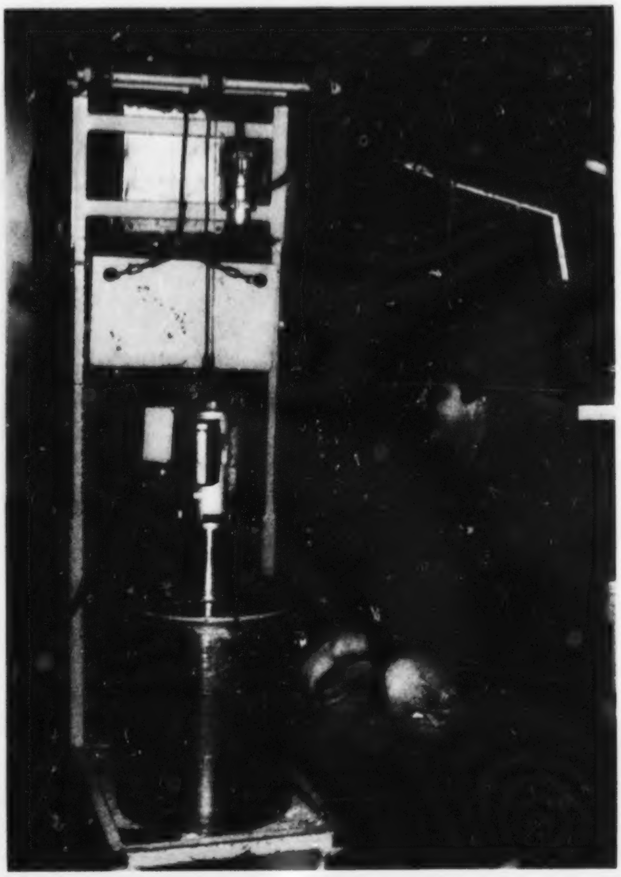


Fig. 13.2 Wet turbine fiberizer ready for operation.

TABLE 8

WX FIBRE LENGTH BEFORE AND AFTER PALLMANN FIBERIZATION

McNETT; % RETAINED ON MESH

SAMPLE	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	GEOMETRIC MEAN (mm)
BEFORE PALLMANN							
LOT #1	5.3	29.7	26.9	8.4	3.1	26.6	0.711
LOT #2	5.4	29.1	27.8	8.8	2.9	26.0	0.719
$\bar{x}$	5.35	29.40	27.35	8.60	3.00	26.30	0.715
s	0.07	0.42	0.64	0.28	0.14	0.42	0.006
AFTER PALLMANN							
SAMPLE #1	0.1	5.2	27.9	14.1	5.8	47.0	0.223
SAMPLE #2	0.0	5.2	26.6	14.6	5.4	48.2	0.215
$\bar{x}$	0.05	5.20	27.25	14.35	5.60	47.60	0.219
s	0.07	0.00	0.92	0.35	0.28	0.85	0.006

TABLE 9

WZ FIBRE LENGTH BEFORE AND AFTER PALLMANN FIBERIZATION

McNETT; % RETAINED ON MESH

SAMPLE	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	GEOMETRIC MEAN (mm)
BEFORE PALLMANN							
COMP.#1	3.6	12.9	27.9	36.5	5.1	14.0	0.584
COMP.#2	3.3	12.7	28.3	34.6	5.1	16.0	0.556
$\bar{x}$	3.45	12.80	28.10	35.55	5.10	15.00	0.570
s	0.21	0.14	0.28	1.34	0.00	1.41	0.020
AFTER PALLMANN							
SAMPLE #1	0.8	8.4	25.9	38.1	5.6	21.2	0.407
SAMPLE #2	0.3	7.9	25.3	37.7	5.9	22.9	0.379
SAMPLE #3	0.3	7.7	25.2	37.8	6.2	22.8	0.377
$\bar{x}$	0.47	8.00	25.47	37.87	5.90	22.30	0.388
s	0.29	0.36	0.38	0.21	0.30	0.95	0.017

TABLE 10

WX FIBRE LENGTH DISTRIBUTION AND HOMOGENEITY BEFORE AND AFTER TURBINE FIBERIZATION

	McNETT; % RETAINED ON MESH						GEOMETRIC MEAN (mm)
SAMPLE	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	
BEFORE WET FIBERIZING WITH THE TURBINE							
1	4.7	13.9	28.9	35.8	5.5	11.2	0.659
2	2.9	13.4	28.9	35.3	5.4	14.1	0.582
3	3.6	13.1	27.4	33.9	5.7	16.3	0.554
4	3.6	14.5	29.0	36.2	5.3	11.4	0.646
5	3.4	14.1	28.0	35.1	5.1	14.3	0.594
6	3.0	13.7	28.0	34.1	4.6	16.6	0.558
7	3.4	14.1	27.7	34.7	4.6	15.5	0.581
8	4.2	14.6	29.0	36.6	5.3	10.3	0.674
9	3.6	13.5	28.6	34.8	4.8	14.7	0.590
$\bar{X}$	3.60	13.88	28.39	35.17	5.14	13.82	0.604
s	0.56	0.50	0.62	0.91	0.40	2.32	0.044
AFTER TURBINE							
1	2.3	10.3	22.6	34.7	7.1	23.0	0.409
2	2.0	9.7	23.2	33.3	6.5	25.3	0.386
3	2.0	10.4	22.3	37.3	7.2	20.8	0.423
4	1.8	10.1	23.0	35.6	6.7	22.8	0.406
5	2.0	10.2	23.5	34.4	7.3	22.6	0.411
6	1.9	9.9	22.7	35.7	6.6	23.2	0.401
7	2.3	9.9	21.1	35.2	6.3	25.2	0.384
8	1.7	9.6	22.1	36.4	6.7	23.5	0.391
9	1.6	10.2	22.5	35.8	6.5	23.4	0.398
$\bar{X}$	1.96	10.03	22.56	35.38	6.77	23.31	0.401
s	0.24	0.27	0.70	1.16	0.35	1.36	0.013

TABLE 11

WZ FIBRE LENGTH DISTRIBUTION AND HOMOGENEITY BEFORE AND AFTER TURBINE FIBERIZATION

McNETT; % RETAINED ON MESH

SAMPLE	+4M	-4M +16M	-16M +40M	-40M +100M	-100M +200M	-200M	GEOMETRIC MEAN (mm)
BEFORE WET FIBERIZING WITH THE TURBINE:							
1	0.5	4.6	20.7	40.2	8.9	25.1	0.313
2	0.6	3.8	16.5	34.1	7.3	37.7	0.232
3	0.5	4.9	20.1	37.6	8.6	28.3	0.295
4	0.3	4.9	20.1	42.0	7.2	25.5	0.314
5	0.3	4.8	21.4	43.4	9.0	21.1	0.342
6	0.6	5.0	22.4	42.3	9.1	20.6	0.353
7	0.5	4.8	18.8	38.1	7.7	30.1	0.282
8	0.9	5.0	21.3	42.0	11.9	18.9	0.355
9	0.6	5.1	22.4	42.5	9.0	20.4	0.356
$\bar{x}$	0.53	4.77	20.41	40.24	8.74	25.30	0.316
s	0.18	0.39	1.87	3.06	1.41	6.03	0.042
AFTER TURBINE:							
1	0.3	2.9	14.5	37.7	8.5	36.1	0.225
2	0.2	3.2	14.9	38.1	8.8	34.8	0.233
3	0.3	2.3	12.4	39.1	8.0	37.9	0.211
4	0.3	2.5	14.2	38.9	7.9	36.2	0.223
5	0.4	2.4	14.0	37.2	7.8	38.2	0.214
6	0.4	2.6	13.3	40.7	8.6	34.4	0.229
7	0.4	3.0	12.5	35.9	8.6	39.6	0.206
8	0.5	3.1	14.8	37.7	9.0	34.9	0.233
9	0.5	3.0	13.6	37.9	8.1	36.9	0.222
$\bar{x}$	0.37	2.78	13.80	38.13	8.37	36.56	0.222
s	0.10	0.33	0.92	1.34	0.43	1.76	0.010

against those received for the initial project, their respective degrees of fiberization and length distributions were compared. The comparative degrees of fiberization are presented in Table 12. The following differences may be observed:

(a) The AK of the initial project was substantially less fiberized than the AK-100 of the project extension.

(b) The AX of the initial project was less fiberized than that of the extension.

(c) The initial AX was substantially less fiberized than the AX-100.

Therefore, in general the fibres for the project extension were more highly fiberized.

FIBRE LENGTH DISTRIBUTION:

The fibre length distributions were also compared and their McNett wet classification results are presented in Table 13. It may be observed that for fibres with the same type of fiberization the geometric mean lengths are not significantly different. However, if the +4mesh fractions are compared we find that grades received for the project extension with the exception of the WX, contain a somewhat higher fraction of +4mesh fibre.

Phase 3, Part 1

FIBRE STRENGTH UNIT EVALUATION:

The AK-100 and AX-100 received for the project extension were submitted to Fibre Strength Unit testing in accordance with the ASTM standard method D3880, and the following results were obtained:

ABLE 12

COMPARATIVE DEGREES OF FIBERIZATION OBTAINED ON FIBRES RECEIVED FOR THE INITIAL PROJECT AND THE PROJECT EXTENSION

		RAPID SURFACE AREA, dm2/g			
		INITIAL PROJECT		PROJECT EXTENSION	
GRADE	FIBERIZATION	BEFORE FIBERIZATION	AFTER FIBERIZATION	BEFORE FIBERIZATION	AFTER FIBERIZATION
<	WILLOW	47	143		
<-100	WILLOW	--	--	108	170
X	WILLOW	38	93	45	112
	PALLMANN	--	--	--	>260
X-100	WILLOW	--	--	101	153
X	PALLMANN	--	--	--	234
T	WILLOW	70	145	70	145

TABLE 13

COMPARISON IN FIBRE LENGTH DETERMINATION BETWEEN FIBRES FOR THE INITIAL PROJECT AND THOSE FOR THE PROJECT EXTENSION

[illegible]RADE	FIBERIZATION	PROJECT	McNETT; % RETAINED ON MESH +4M	 -4M +16M	 -16M +40M	 -40M +100M	 -100M +200M	 -200M	GEOMETRIC MEAN (mm)
AK	WILLOW	INITIAL	27.8	23.0	13.7	6.8	3.5	25.2	1.075
[illegible]K-100	WILLOW	EXTENSION	30.9	21.2	13.4	7.7	3.0	23.8	1.167
AX	WILLOW	INITIAL	2.7	19.7	33.9	11.9	3.6	28.2	0.538
[illegible]X	WILLOW	EXTENSION	4.3	19.6	30.3	11.7	4.5	29.6	0.524
[illegible]X	PALLMANN	EXTENSION	0.1	5.2	27.2	14.3	5.6	47.6	0.219
AX-100	WILLOW	EXTENSION	4.9	16.6	32.0	13.8	4.3	28.4	0.519
[illegible]X	AS RECEIVED	INITIAL	8.3	17.6	21.7	28.7	5.2	18.5	0.643
WX	AS RECEIVED	EXTENSION	3.8	13.3	28.8	35.5	5.2	13.4	0.606
[illegible]X	PALLMANN	EXTENSION	0.5	8.0	25.5	37.9	5.9	22.2	0.389
[illegible]X	TURBINE	EXTENSION	2.0	10.0	22.6	35.4	6.8	23.2	0.402
WZ	AS RECEIVED	INITIAL	0.2	2.7	11.2	43.3	12.6	30.0	0.235
[illegible]Z	AS RECEIVED	EXTENSION	0.4	4.9	21.9	42.1	8.7	22.0	0.340
WZ	TURBINE	EXTENSION	0.4	2.8	13.8	38.1	8.4	36.5	0.222
[illegible]T	WILLOW	INITIAL	12.5	14.7	16.8	10.0	4.8	41.2	0.410
[illegible]T	WILLOW	EXTENSION	12.5	14.7	16.8	10.0	4.8	41.2	0.410

GRADE	AK-100	AX-100
Fibre ratio, Qf, %	9	10
Flexural modulus of rupture adjusted (MR_A) to 1.6 g/cm^3, kgf/cm^2	279	289
MP_a	27.4	28.3
Fibre Strength Unit, units	112	105
Point value, points	74	68

The Fibre Strength Unit performance of the fibres tested in the initial project and in the project extension are presented hereunder in decreasing order of Fibre Strength Unit:

GRADE	PROJECT	FIBERIZATION	FIBRE RATIO Qf,%	FIBRE STRENGTH UNIT UNITS
AK-100	extension	Willow	9.0	112
AK	initial	Willow	9.3	108
AX-100	extension	Willow	10.0	105
WX	initial	as received	9.9	101
4T	both	Willow	11.7	85.5
WZ	initial	as received	11.7	85.4
AX	initial	Willow	16.1	62.0

Phase 3, Part 2

MACHINE PRODUCTION AND TESTING OF AUTOCLAVED SHEET PRODUCTS

FLAT SHEET FORMULATIONS:

Flat asbestos-cement sheets, both pressed and non pressed, were produced from the following fibre furnishes in the Hatschek pilot plant:

GRADE	FIBERIZATION	FIBRE RATIO, %
AK-100	Willow	8
AX	Willow	14
	Willow	18
	Pallmann	16
AX-100	Willow	14
WX	as received	14
	as received	18
	Pallmann	16
	turbine	16
WZ	as received	14
	as received	18
	turbine	16

In every case the binder (an autoclavable calcium silicate binder) was composed of normal type 10 Portland cement and silica flour in the ratio of 3:2 respectively.

FLAT SHEET PROCESS:

The autoclaving was carried out in saturated steam at 176.7°C and 0.82 MPa (100psig or 115 psia) during 10h. The dry ingredients (fibre, cement and silica) were premixed in the vertical mixer for 15 min. Felt speed was kept at 24m/min. The accumulator roll pressure was maintained at 11.5kg/cm.

FLAT SHEET PRODUCTION PARAMETERS:

The following production statistics were noted:

PARAMETER	RANGE			STANDARD
	MIN	MAX	AVERAGE	DEVIATION
Feed slurry consistency, %	5.9	7.8	7.1	0.5
White water concentration, %	0.66	2.25	0.96	0.44
Thickness, mm	8.3	9.6	8.9	0.4
Total number of plies	40	68	53	7
Number of plies /6mm	28	45	36	5
Plies/mm	4.6	7.5	6.0	0.8

In the case of the pressed products, these were pressed 15 min at 17.1 MPa (248 psi). All of the above production data are presented in detail in tabular form in Table 14.

FLEXURAL TESTS ON FLAT SHEETS:

The flexural resistance of the flat sheets produced was determined by the third point loading technique on a 10cm span at a crosshead speed of 1mm/min. The specimens were tested in the saturated condition and in the machine and cross directions. The flexural moduli of rupture as tested (not adjusted for density), MR_T, are presented in Table 15. The flexural moduli of rupture adjusted (MR_A) to a reference density of 1.6g/cm^3 are presented in Table 16. The comparison in flexural moduli of rupture between the pressed and unpressed products is presented in Table 17. Table 18 compares the density and porosity of pressed Versus non pressed products. The grand average flexural moduli of rupture for pressed and unpressed as well as for products tested in the machine and cross directions are presented in Table 19, and Fig. 14.

TABLE 14

DETAILED PRODUCTION PARAMETERS FOR AUTOCLAVED FLAT SHEETS

GRADE	FIBERIZATION	FIBRE RATIO (%)	CEMENT (%)	SILICA (%)	FEED SLURRY CONSISTENCY (%)	WHITE WATER CONCENTRATION (%)	TICKNESS (mm)	TOTAL NUMBER OF PLIES	PLIES PER 6mm	PLIES PER mm
AX	WILLOW	14	51.6	34.4	7.4	1.08	9.3	50	32	5.4
AX	WILLOW	18	49.2	32.8	7.8	0.86	9.1	49	32	5.4
AX	PALLMANN	16	50.4	33.6	7.1	0.82	9.6	68	43	7.1
AX-100	WILLOW	14	51.6	34.4	7.5	1.13	8.4	53	38	6.3
AK-100	WILLOW	8	55.2	36.8	7.3	2.25	8.3	62	45	7.5
WX	AS RECEIVED	14	51.6	34.4	7.0	1.04	8.3	53	38	6.4
WX	AS RECEIVED	18	49.2	32.8	7.0	0.69	8.7	40	28	4.6
WX	PALLMANN	16	50.4	33.6	5.9	0.70	9.1	56	37	6.2
WX	TURBINE	16	50.4	33.6	7.4	0.79	8.9	49	33	5.5
WZ	AS RECEIVED	14	51.6	34.4	7.8	0.90	9.1	48	32	5.3
WZ	AS RECEIVED	18	49.2	32.8	6.8	0.66	8.7	50	34	5.7
WZ	TURBINE	16	50.4	33.6	6.4	0.68	9.1	58	38	6.4

NOTES:

1- BINDER WAS COMPOSED OF NORMAL (TYPE 10) PORTLAND CEMENT AND SIL-CO-SIL SILICA FLOUR IN THE RATIO OF 3:2

2- AUTOCLAVING WAS CARRIED OUT IN SATURATED STEAM AT 176.7°C AND 0.82 MPa (100 psia)DURING 10 H.

3- FIBRE,CEMENT AND SILICA WERE PREMIXED IN A NORIA FOR 15 MIN.

4- FELT SPEED WAS KEPT AT 24m/min AND ACCUMULATOR PRESSURE AT 11.5 kg/cm.

5- IN THE CASE OF PRESSED PRODUCTS (ONLY),THESE WERE PRESSED 15 min AT 17.1 MPa (248 psi).

TABLE 15

FLEXURAL MODULI OF RUPTURE AS TESTED (MRt) FOR FLAT AUTOCLAVED SHEETS, MPa.

				NON PRESSED			PRESSED		
GRADE	FIBERIZATION	PROJECT	FIBRE (%)	CROSS DIR	MACHINE DIR	AVG	CROSS DIR	MACHINE DIR	AVG
AK	WILLOW	INITIAL	8	23.7	32.8	28.3	36.5	48.5	42.5
AK-100	WILLOW	EXTENSION	8	23.1	34.8	28.9	38.4	54.2	46.3
AX-100	WILLOW	EXTENSION	14	23.5	38.7	31.1	35.5	47.0	41.2
AX	WILLOW	INITIAL	14	23.8	32.0	27.9	35.7	48.1	41.9
AX	WILLOW	EXTENSION	14	22.9	34.1	28.5	36.1	56.3	46.2
AX	WILLOW	EXTENSION	18	26.8	38.0	32.4	45.0	59.7	52.4
AX	PALLMANN	EXTENSION	16	27.3	33.7	30.5	45.6	55.7	50.7
WX	AS RECEIVED	INITIAL	8	24.4	31.6	28.0	32.5	42.2	37.4
WX	AS RECEIVED	EXTENSION	14	30.5	39.5	35.0	48.0	57.6	52.8
WX	AS RECEIVED	EXTENSION	18	27.3	35.8	31.5	44.3	54.5	50.4
WX	PALLMANN	EXTENSION	16	29.6	38.8	34.2	53.6	66.4	60.0
WX	TURBINE	EXTENSION	16	32.9	38.2	35.5	52.8	63.5	58.2
WZ	AS RECEIVED	INITIAL	10	30.4	33.1	31.8	37.0	45.2	41.1
WZ	AS RECEIVED	EXTENSION	14	29.9	35.2	32.6	46.6	55.9	51.3
WZ	AS RECEIVED	EXTENSION	18	28.9	38.4	33.6	48.8	60.2	54.5
WZ	TURBINE	EXTENSION	16	32.7	35.2	33.9	48.0	55.9	51.9
4T	WILLOW	BOTH	10	18.8	24.2	21.5	27.2	35.8	31.5

TABLE 16

FLEXURAL MODULI OF RUPTURE ADJUSTED (MRA) TO A REFERENCE DENSITY OF 1.6 g/cm3 FOR FLAT AUTOCLAVED SHEETS, MPa.

				NON PRESSED			PRESSED		
GRADE	FIBERIZATION	PROJECT	FIBRE (%)	CROSS DIR	MACHINE DIR	AVG	CROSS DIR	MACHINE DIR	AVG
AK	WILLOW	INITIAL	8	33.6	46.5	40.1	37.5	49.7	43.6
AK-100	WILLOW	EXTENSION	8	32.5	48.9	40.7	39.4	55.6	47.5
AX-100	WILLOW	EXTENSION	14	30.7	50.7	40.7	32.8	43.5	38.2
AX	WILLOW	INITIAL	14	32.1	43.2	37.7	35.3	47.6	41.5
AX	WILLOW	EXTENSION	14	32.1	47.8	40.0	37.0	57.6	47.3
AX	WILLOW	EXTENSION	18	40.8	57.9	49.4	47.6	63.0	55.3
AX	PALLMANN	EXTENSION	16	37.3	46.1	41.7	42.9	52.4	47.7
WX	AS RECEIVED	INITIAL	8	29.8	38.6	34.2	30.6	39.8	35.2
WX	AS RECEIVED	EXTENSION	14	41.1	53.3	47.2	47.7	57.3	52.5
WX	AS RECEIVED	EXTENSION	18	39.6	51.9	45.8	45.6	56.0	50.8
WX	PALLMANN	EXTENSION	16	44.4	58.2	51.3	53.2	65.9	59.6
WX	TURBINE	EXTENSION	16	45.4	52.8	49.1	51.7	62.2	57.0
WZ	AS RECEIVED	INITIAL	10	33.1	36.0	34.6	31.2	38.0	34.6
WZ	AS RECEIVED	EXTENSION	14	40.7	47.9	44.3	46.3	55.6	51.0
WZ	AS RECEIVED	EXTENSION	18	43.1	57.2	50.2	51.4	63.4	57.4
WZ	TURBINE	EXTENSION	16	46.3	49.8	48.1	49.1	57.2	53.2
4T	WILLOW	BOTH	10	29.0	37.2	33.1	30.3	40.0	35.2

TABLE 17

FLEXURAL MODULI OF RUPTURE FOR FLAT AUTOCLAVED SHEETS, COMPARING PRESSED AGAINST NON PRESSED PRODUCTS, MPa.

				MODULUS OF RUPTURE AS TESTED (MRt)			MODULUS OF RUPTURE ADJUSTED (MRa) FOR A REFERENCE DENSITY OF 1.6 g/cm3.		
GRADE	FIBERIZATION	PROJECT	FIBRE (%)	NON PRESSED	PRESSED	DIFF (%)	NON PRESSED	PRESSED	DIFF (%)
AK	WILLOW	INITIAL	8	28.3	42.5	50.2	40.1	43.6	8.7
AK-100	WILLOW	EXTENSION	8	28.9	46.3	60.2	40.7	47.5	16.7
AX-100	WILLOW	EXTENSION	14	31.1	41.2	32.5	40.7	38.2	-6.1
AX	WILLOW	INITIAL	14	27.9	41.9	50.2	37.7	41.5	10.1
AX	WILLOW	EXTENSION	14	28.5	46.2	62.1	40.0	47.3	18.2
AX	WILLOW	EXTENSION	18	32.4	52.4	61.7	49.3	55.3	12.2
AX	PALLMANN	EXTENSION	16	30.5	50.7	66.2	41.7	47.6	14.1
WX	AS RECEIVED	INITIAL	8	28.0	37.4	33.6	34.2	35.2	2.9
WX	AS RECEIVED	EXTENSION	14	35.0	52.8	50.9	47.2	52.5	11.2
WX	AS RECEIVED	EXTENSION	18	31.5	50.4	60.0	45.8	50.8	10.9
WX	PALLMANN	EXTENSION	16	34.2	60.0	75.4	51.3	59.6	16.2
WX	TURBINE	EXTENSION	16	35.5	58.2	63.9	49.1	57.0	16.1
WZ	AS RECEIVED	INITIAL	10	31.8	41.1	29.2	34.5	34.6	0.3
WZ	AS RECEIVED	EXTENSION	14	32.6	51.3	57.4	44.3	50.9	14.9
WZ	AS RECEIVED	EXTENSION	18	33.6	54.5	62.2	50.2	57.4	14.3
WZ	TURBINE	EXTENSION	16	33.9	51.9	53.1	48.1	53.2	10.6
4T	WILLOW	BOTH	10	21.5	31.5	46.5	33.1	35.2	6.3

TABLE 18

DENSITY AND POROSITY OF FLAT AUTOCLAVED SHEETS,COMPARING PRESSED AGAINST UNPRESSED PRODUCTS.

				DENSITY g/cm3			POROSITY, (%)		
GRADE	FIBERIZATION	PROJECT	FIBRE (%)	NON PRESSED	PRESSED	DIFF (%)	NON PRESSED	PRESSED	DIFF (%)
AK	WILLOW	INITIAL	8	1.34	1.58	17.9	34.9	24.9	-28.7
AK-100	WILLOW	EXTENSION	8	1.35	1.58	17.0	35.6	25.8	-27.5
AX-100	WILLOW	EXTENSION	14	1.40	1.66	18.6	31.5	21.8	-30.8
AX	WILLOW	INITIAL	14	1.38	1.61	16.7	32.5	24.0	-26.2
AX	WILLOW	EXTENSION	14	1.35	1.58	17.0	33.6	25.2	-25.0
AX	WILLOW	EXTENSION	18	1.30	1.56	20.0	36.7	26.0	-29.2
AX	PALLMANN	EXTENSION	16	1.37	1.65	20.4	34.2	22.9	-33.0
WX	AS RECEIVED	INITIAL	8	1.45	1.65	13.8	29.7	22.3	-24.9
WX	AS RECEIVED	EXTENSION	14	1.38	1.60	15.9	33.2	24.6	-25.9
WX	AS RECEIVED	EXTENSION	18	1.33	1.59	19.5	35.6	24.4	-31.5
WX	PALLMANN	EXTENSION	16	1.31	1.61	22.9	36.5	23.6	-35.3
WX	TURBINE	EXTENSION	16	1.36	1.62	19.1	34.6	24.2	-30.1
WZ	AS RECEIVED	INITIAL	10	1.54	1.74	13.0	27.8	20.9	-24.8
WZ	AS RECEIVED	EXTENSION	14	1.37	1.60	16.8	32.6	23.8	-27.0
WZ	AS RECEIVED	EXTENSION	18	1.31	1.56	19.1	36.1	25.9	-28.3
WZ	TURBINE	EXTENSION	16	1.34	1.58	17.9	35.0	25.3	-27.7
4T	WILLOW	BOTH	10	1.29	1.51	17.1	38.5	28.7	-25.5

TABLE 19

GRAND AVERAGE FLEXURAL MODULI OF RUPTURE FOR PRESSED,UNPRESSED, MACHINE DIRECTION AND CROSS DIRECTION.

FLEXURAL MODULI OF RUPTURE,MPa

				AS TESTED (MRt)		ADJUSTED TO THE REFERENCE DENSITY OF 1.6 g/cm (MRa)		GRAND AVERAGE	
GRADE	FIBERIZATION	PROJECT	FIBRE (%)	NON PRESSED AVG	PRESSED AVG	NON PRESSED AVG	PRESSED AVG	(MRt)	(MRa)
AK	WILLOW	INITIAL	8	28.3	42.5	40.1	43.6	35.4	41.9
A[illegible]-100	WILLOW	EXTENSION	8	28.9	46.3	40.7	47.5	37.6	44.1
AX-100	WILLOW	EXTENSION	14	31.1	41.2	40.7	38.2	36.2	39.5
A[illegible]	WILLOW	INITIAL	14	27.9	41.9	37.7	41.5	34.9	39.6
A[illegible]	WILLOW	EXTENSION	14	28.5	46.2	40.0	47.3	37.4	43.7
AX	WILLOW	EXTENSION	18	32.4	52.4	49.3	55.3	42.4	52.3
A[illegible]	PALLMANN	EXTENSION	16	30.5	50.7	41.7	47.6	40.6	44.7
WX	AS RECEIVED	INITIAL	8	28.0	37.4	34.2	35.2	32.7	34.7
W[illegible]	AS RECEIVED	EXTENSION	14	35.0	52.8	47.2	52.5	43.9	49.9
WX	AS RECEIVED	EXTENSION	18	31.5	50.4	45.8	50.8	41.0	48.3
WX	PALLMANN	EXTENSION	16	34.2	60.0	51.3	59.6	47.1	55.5
W[illegible]	TURBINE	EXTENSION	16	35.5	58.2	49.1	57.0	46.9	53.1
WZ	AS RECEIVED	INITIAL	10	31.8	41.1	34.5	34.6	36.5	34.6
W[illegible]	AS RECEIVED	EXTENSION	14	32.6	51.3	44.3	50.9	42.0	47.6
WZ	AS RECEIVED	EXTENSION	18	33.6	54.5	50.2	57.4	44.1	53.8
WZ	TURBINE	EXTENSION	16	33.9	51.9	48.1	53.2	42.9	50.7
[illegible]	WILLOW	BOTH	10	21.5	31.5	33.1	35.2	26.5	34.2

FIG. 14

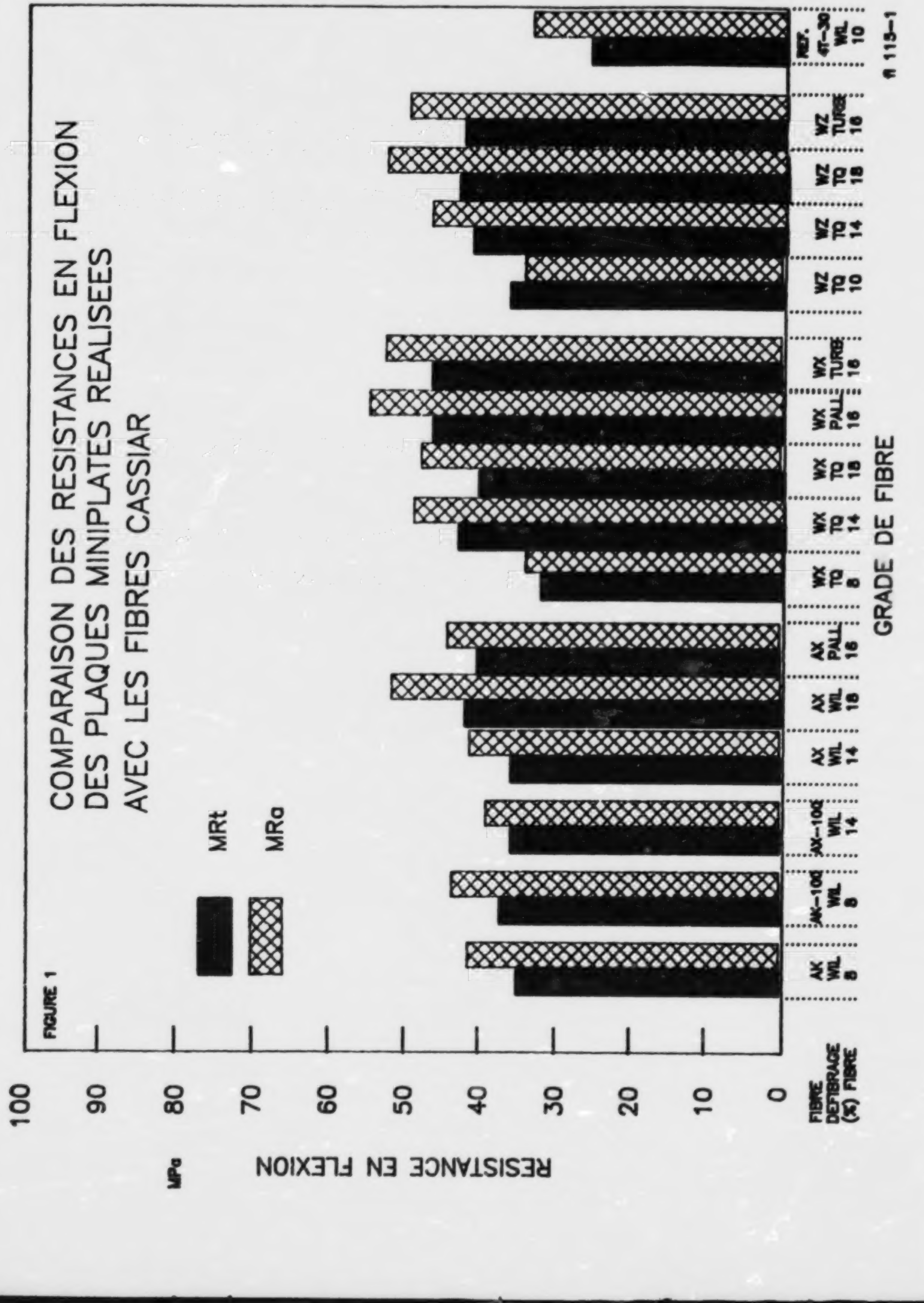


FIGURE 1
COMPARAISON DES RESISTANCES EN FLEXION
DES PLAQUES MINIPLATES REALISEES
AVEC LES FIBRES CASSIAR
MRt
MRa
MPa
RESISTANCE EN FLEXION
100
90
80
70
60
50
40
30
20
10
0
FIBRE
DEFIBRAGE
(%) FIBRE
AX WIL 8
AX-100 WIL 8
AX-100 WIL 14
AX WIL 14
AX WIL 18
AX PALL 16
WX TQ 8
WX TQ 14
WX TQ 18
WX PALL 16
WX TURB 18
WZ TQ 10
WZ TQ 14
WZ TQ 18
WZ TURB 16
REF. 4T-30 WIL 10
GRADE DE FIBRE
fl 115-1

Phase 3, Part 3

PRODUCTION AND TESTING OF PIPES

PIPE FORMULATIONS:

Pipes were produced on the pilot Hatschek machine using the following fibre furnishes:

GRADE	FIBERIZATION	FIBRE RATIO, %
AK-100		
AX	Willow	14
AX	Willow	18
AX	Pallmann	16
AX-100	Willow	16
WX	As received	14
WX	As received	18
WX	Pallmann	16
WX	Turbine	16
WZ	As received	14
WZ	As received	18
WZ	Turbine	16

In each case the (calcium silicate) binder case composed of normal (type 10) Portland cement and Sil-Co-Sil silica flour in the ratio of 3:2. The pipes were autoclaved in saturated steam at 176.7°C and 0.82MPa (100psig or 115 psia) during 10h. The fibre, cement and silica were dry blended in a drum mixer during 10 min followed by wet premixing in a vertical mixer before final wet mixing in the ribbon blender. In some cases, release from the mandrel was experienced before the required thickness was achieved.

PIPE PRODUCTION PARAMETERS:

The following production statistics were noted:

PARAMETER	RANGE		AVERAGE	STANDARD DEVIATION
	MIN	MAX		
Feed slurry consistency, %	5.3	10.5	7.1	1.2
White water concentration,%	0.45	1.158	0.83	0.27
Thickness, mm	13.9	24.2	19.2	3.1
Total number of plies	64	195	122	37
Number of plies/mm	4.0	9.2	6.1	2.0
Green hardness, durometer type C	24	49	34	5

In order to estimate the magnitude of the plastic deformation occuring, the length of the pipes were determined and are presented in Table 21A. Length extension appears to vary proportionally with the degree of plastic deformation. Table 21B presents runability observations.

The following remarks were noted during the production of the pipes.

GRADE	REMARKS
AK	Good fibre dispersion. Good runability.
AK-100	High feed slurry consistencies did not run well. The optimum consistency appears to be in the order of 6%.

TABLE 20

DETAILED PRODUCTION PARAMETERS FOR PIPES

No	GRADE	FIBERIZATION	OF FIBRE RATIO (%)	CEMENT (%)	SILICA (%)	FEED SLURRY CONSISTENCY (%)	WHITE WATER CONCENTRATION (%)	THICKNESS (mm)	TOTAL NUMBER OF PLIES	PLIES PER (mm)	GREEN HARDNESS DUROMETER TYPE C
REF	AK	WILLOW	16	50.4	33.6	7.0	1.58	23.9	158	6.6	38
17	AK-100	WILLOW	16	50.4	33.6	5.3	0.98	21.7	162	7.5	43
18	AK-100	WILLOW	16	50.4	33.6	7.3	1.16	13.9	100	7.2	49
18R	AK-100	WILLOW	16	50.4	33.6	6.0	1.01	15.4	115	7.5	36
31	AX	WILLOW	14	51.6	34.4	7.5	1.39	22.3	145	6.5	34
32	AX	WILLOW	14	51.6	34.4	5.9	1.11	22.6	144	6.4	31
33	AX	WILLOW	18	49.2	32.8	5.7	0.99	22.3	160	7.2	35
34	AX	WILLOW	18	49.2	32.8	5.4	0.83	22.9	152	6.6	35
29	AX	PALLMANN	16	50.4	33.6	6.3	0.68	17.3	127	7.3	36
30	AX	PALLMANN	16	50.4	33.6	6.7	0.50	14.5	115	7.9	45
30R	AX	PALLMANN	16	50.4	33.6	7.3	0.83	20.6	190	9.2	30
19	AX-100	WILLOW	16	50.4	33.6	8.5	1.06	18.6	126	6.8	39
20	AX-100	WILLOW	16	50.4	33.6	6.9	1.02	23.8	152	6.4	24
21	WX	AS RECEIVED	14	51.6	34.4	9.4	0.91	18.7	102	5.5	36
22	WX	AS RECEIVED	14	51.6	34.4	8.5	0.86	20.9	109	5.5	34
23	WX	AS RECEIVED	18	49.2	32.8	8.6	0.83	20.2	110	5.4	30
24	WX	AS RECEIVED	18	49.2	32.8	7.6	0.66	14.9	64	4.3	41
24R	WX	AS RECEIVED	18	49.2	32.8	6.5	0.60	18.2	100	5.5	35
25	WX	PALLMANN	16	50.4	33.6	6.5	0.64	18.4	101	5.5	36
25R	WX	PALLMANN	16	50.4	33.6	5.9	0.64	17.0	104	6.1	35
26	WX	PALLMANN	16	50.4	33.6	6.8	0.74	19.9	139	7.0	33
27	WX	TURBINE	16	50.4	33.6	7.9	0.51	18.3	108	5.9	32
28	WX	TURBINE	16	50.4	33.6	7.2	0.52	19.1	125	6.5	35
35	WZ	AS RECEIVED	14	51.6	34.4	7.2	0.89	24.2	195	8.1	27
36	WZ	AS RECEIVED	14	51.6	34.4	6.8	0.98	17.9	148	8.3	29
37	WZ	AS RECEIVED	18	49.2	32.8	6.7	0.69	22.4	159	7.1	31
38	WZ	AS RECEIVED	18	49.2	32.8	6.1	0.62	15.6	109	7.0	37
38R	WZ	AS RECEIVED	18	49.2	32.8	7.2	0.45	19.7	94	4.8	27
39	WZ	TURBINE	16	50.4	33.6	7.0	0.67	16.4	118	7.2	29
40	WZ	TURBINE	16	50.4	33.6	10.5	0.47	16.7	66	4.0	32

NOTES1. BINDER COMPOSED OF NORMAL (TYPE 10) PORTLAND CEMENT AND SIL-CO-SIL SILICA FLOUR IN THE RATIO OF 3:2

2. AUTOCLAVING IN SATURATED STEAM AT 176.7°C AND 0.82 MPa(100psig OR 115 psia) FOR 10 H.

3. FIBRE,CEMENT AND SILICA PREMIXED DRY IN A MIXING DRUM FOR 10 MIN AND WET PREMIXED IN THE NORIA FOR 1 MIN.

4. FELT SPEED WAS KEPT AT 17 m /min AND ACCUMULATOR PRESSURE AT 23 kg/cm.

5. MANDREL DIAMETER WAS 20.3 cm (8 in).

TABLE 21-A

PIPE LENGTH EXTENSION PRESENTED AS A FUNCTION OF PLASTIC DEFORMATION

GRADE	PIPE No.	FIBERIZATION	FIBRE RATIO (%)	PIPE LENGTH, cm a	b	c	mean	LENGTH EXTENSION (PLASTIC) DEFORMATION cm
AK	REF	WILLOW	16	52.0	----	----	52.0	0.0
AK-100	17-18-18R	WILLOW	16	52.0	52.0	52.0	52.0	0.0
AX	31-32	WILLOW	14	52.0	52.0	----	52.0	0.0
	33-34	WILLOW	18	52.0	52.0	----	52.0	0.0
	29-30-30R	PALLMANN	16	54.0	53.5	56.0	54.5	2.5
AX-100	19-20	WILLOW	16	53.5	54.5	----	54.0	2.0
WX	21-22	AS RECEIVED	14	55.5	----	----	55.5	3.5
	23-24-24R	AS RECEIVED	18	----	----	53.0	53.0	1.0
	25-25R-26	PALLMANN	16	55.0	----	56.5	55.8	3.8
	27-28	TURBINE	16	60.0	58.0	----	59.0	7.0
WZ	35-36	AS RECEIVED	14	57.5	----	----	57.5	5.5
	37-38-38R	AS RECEIVED	18	57.5	----	58.0	57.8	5.8
	39-40	TURBINE	16	58.0	59.5	----	58.8	6.8

TABLE 21-B RUNABILITY

AK	ALL	WILLOW	16	GOOD RUNABILITY
AK-100	"	WILLOW	16	" "
AX	"	WILLOW	14	" "
	"		16	PREMATURE MANDREL RELASE
	"		18	GOOD RUNABILITY
	"	PALLMANN	16	POOR RUANABILITY, PREMATURE MANDREL RELASE AND PLASTIC DEFORMATION.
WX	"	AS RECEIVED	14	" " "
	"		16	" " "
	"		18	" " "
	"	PALLMANN	16	" " "
	"	TURBINE	16	" " "
WZ	"	AS RECEIVED	14	" " "
	"		16	" " "
	"		18	" " "
	"	TURBINE	16	" " "
4T	"	WILLOW	16	GOOD RUNABILITY

GRADE	REMARKS
AX	Fiberized in the Willow: Good runability with 14 and 18% fibre. The premature mandrel release experienced with 16% fibre during the initial project may be attributed to the shortage of +4mesh fibre in the AX received for the initial project (for which the +4mesh McNett fraction was 45% lower as shown in Table 13). Fiberized in the Pallmann: Premature mandrel release and 2.5cm of plastic deformation were noted. Again these shortcomings are attributed to the reduction in +4mesh fibre caused by Pallmann fiberization as shown in Table 13.
AX-100	Good runability. Some 2cm of plastic deformation was observed.
WX	Premature mandrel release was observed in all cases. Plastic deformation ranged between 1 and 7cm. The 1cm deformation was obtained with 18% fibre opened in the Willow, and this is acceptable. The 7cm extension resulted from the turbine wet fiberized product.
WZ	Premature mandrel release was observed. Plastic deformation average 5.7 cm for fibres as received and 6.8 cm for fibres opened wet in the turbine.

PIPE DENSITY TESTS:

The density of the pipes is presented in Table 22 together with the

TABLE 22

DENSITY OF THE PIPES PRODUCED DURING THE INITIAL PROJECT AND THE PROJECT EXTENSION

GRADE	PIPE No	FIBERIZATION	FIBRE RATIO (%)	PIPE DENSITY (g/cm3) a	b	c	AVG
AK	11*12*-REF	WILLOW	16	1.512	1.421	1.391	1.441
AK-100	17-18-18R	WILLOW	16	1.390	1.471	1.469	1.443
AX	31-32	WILLOW	14	1.521	1.489	----	1.505
	7*-8*	WILLOW	16	1.564	1.595	----	1.580
	33-34	WILLOW	18	1.445	1.442	----	1.444
	29-30-30R	PALLMANN	16	1.425	1.520	1.491	1.479
AX-100	19-20	WILLOW	16	1.528	1.502	----	1.515
WX	21-22	AS RECEIVED	14	1.477	1.489	----	1.483
	13*-14*	AS RECEIVED	16	1.487	1.473		1.480
	23-24-24R	AS RECEIVED	18	1.417	1.413	1.434	1.421
	25-25R-26	PALLMANN	16	1.417	1.432	1.383	1.411
	27-28	TURBINE	16	1.376	1.383	----	1.380
WZ	35-36	AS RECEIVED	14	1.441	1.465	----	1.453
	15*-16*	AS RECEIVED	16	1.465	1.529	----	1.497
	37-38-38R	AS RECEIVED	18	1.382	1.394	1.313	1.363
	39-40	TURBINE	16	1.353	1.357	----	1.355
4T	4*-9*-10*	WILLOW	16	1.520	1.568	1.467	1.518

NOTES: (1*) PIPE NUMBERS WITH AN ASTERISK WERE PRODUCED DURING THE INITIAL PROJECT AND ARE PRESENTED HERE FOR COMPARISON.

(2) PIPES PRODUCED DURING THE PROJECT EXTENSION RANGE IN DENSITY BETWEEN 1.313 AND 1.528 g/cm3 AND AVERAGE 1.434 g/cm3 WITH A STANDARD DEVIATION OF 0.055 g/cm3.

density of pipes from the initial project for comparison. Densities ranging between 1.31 and 1.53g/cm and averaging 1.43g/cm^3 with a standard deviation of 0.06g/cm^3 were obtained for pipes produced during the project extension.

PIPE POROSITY TESTS:

The porosity of the pipes is presented in Table 23 together with the porosity of pipes produced during the initial project to allow comparison. Porosities ranging between 24.7 and 33.5% and averaging 29.6% with a standard deviation of 2.5% were obtained for pipes produced during the project extension.

CRUSHING TESTS FOR PIPES:

The crushing strenth of the pipes is presented in Table 24 together with the corresponding data obtained during the initial project for comparison. Crushing strengths per meter of length per cm of thickness ranged from 31.2 to 75.9kN/m.cm and averaged 50 kN/m.cm with a standard deviation of 13kN/m.cm. There were 3 Class 100 pipes, 13 Class 150 pipes and 3 Class 200 pipes, when taking only crushing strength as a classification criteria.

HYDROSTATIC TESTING OF PIPES:

The hydrostatic strength of the pipes is presented in Table 25, together with the corresponding data obtained during the initial project for comparison. If the data for pipes with wall thicknesses of 1.27cm (0.5 in.) are left out the bursting pressures per centimeter of thickness ranged from 1.15 to 2.46 MPa/cm and averaged 1.91 MPa/cm with a standard deviation of 0.30 MPa/cm. Three pipes had insufficient thickness, one pipe was of Class 100, twelve pipes were of Class 150 and one pipe was of Class 200 when taking only the bursting strength per unit thickness

TABLE 23

POROSITY OF THE PIPES PRODUCED DURING THE INITIAL PROJECT AND THE PROJECT EXTENSION

GRADE	PIPE NO	FIBERIZATION	FIBRE RATIO (%)	PIPE POROSITY (%) a	b	c	AVG
AK	11*12*-REF	WILLOW	16	26.1	31.0	31.4	29.5
AK-100	17-18-18R	WILLOW	16	31.0	28.8	28.8	29.5
AX	31-32	WILLOW	14	24.7	26.5	----	25.6
	7*-8*	WILLOW	16	24.6	22.9	----	23.8
	33-34	WILLOW	18	28.4	28.7	----	28.6
	29-30-30R	PALLMANN	16	30.1	26.3	27.6	28.0
AX-100	19-20	WILLOW	16	25.6	26.6	----	26.1
WX	21-22	AS RECEIVED	14	27.8	27.0	----	27.4
	13*-14*	AS RECEIVED	16	28.2	27.7		28.0
	23-24-24R	AS RECEIVED	18	30.5	31.2	29.7	30.5
	25-25R-26	PALLMANN	16	30.7	30.0	32.3	31.0
	27-28	TURBINE	16	32.6	32.4	----	32.5
WZ	35-36	AS RECEIVED	14	28.2	28.4	----	28.3
	15*-16*	AS RECEIVED	16	28.1	26.1	----	27.1
	37-38-38R	AS RECEIVED	18	31.0	31.5	34.8	32.4
	39-40	TURBINE	16	32.8	33.5	----	33.2
4T	4*-9*-10*	WILLOW	16	26.8	24.0	29.4	26.7

NOTES: (1*) PIPE NUMBERS WITH AN ASTERISK WERE PRODUCED DURING THE INITIAL PROJECT AND ARE PRESENTED HERE FOR COMPARISON.

(2) PIPES PRODUCED DURING THE PROJECT EXTENSION RANGE IN POROSITY FROM 24. TO 34.8 AND AVERAGE 29.6% WITH A STANDARD DEVIATION OF 2.5%.

TABLE 24

CRUSHING STRENGTH OF PIPES PRODUCED DURING THE INITIAL PROJECT AND THE PROJECT EXTENSION

GRADE	PIPE NO	FIBERIZATION	FIBRE RATIO (%)	THICKNESS cm	CRUSHING STRENGTH kN/m	CRUSHING PER UNIT kN/m.cm	STRENGTH THICKNESS CLASS
AK	11*	WILLOW	16	1.95	134.8	69.1	200
	12*	WILLOW	16	1.93	144.5	74.9	200
	REF	WILLOW	16	2.05	155.6	75.9	200
AK-100	17	WILLOW	16	2.18	147.7	67.8	200
	18	WILLOW	16	1.39	64.1	46.1	150
AX	31	WILLOW	14	2.19	135.8	62.0	150
	32	WILLOW	14	2.25	128.7	57.2	150
	7*	WILLOW	16	1.49	76.3	51.2	150
	33	WILLOW	18	2.24	148.0	66.1	200
	34	WILLOW	18	2.19	128.1	58.5	150
	29	PALLMANN	16	1.71	74.0	43.3	150
AX-100	19	WILLOW	16	1.62	95.9	59.2	150
WX	21	AS RECEIVED	14	1.85	75.2	40.6	150
	14*	AS RECEIVED	16	1.29	57.0	44.2	150
	23	AS RECEIVED	18	1.95	70.2	36.0	100
	26	PALLMANN	16	1.95	80.8	41.4	150
	28	TURBINE	16	1.86	63.6	34.2	100
WZ	35	AS RECEIVED	14	2.40	121.1	50.5	150
	38	AS RECEIVED	18	1.51	75.4	49.9	150
	38R	AS RECEIVED	18	2.02	79.1	39.2	150
	39	TURBINE	16	1.59	49.6	31.2	100
4T	10*	WILLOW	16	1.95	104.8	53.7	150
CONTROL LIMITS FOR 8-in (20.3-cm)PIPE							
---	---	---	---	1.97 TO 2.12	58.4	27.5	100
---	---	---	---	1.97 TO 2.12	80.3	37.9	150
---	---	---	---	1.97 TO 2.12	135.7	64.0	200

* DATA FROM INITIAL PROJECT

TABLE 25

HYDROSTATIC RESISTANCE (bursting strength) OF PIPES PRODUCED DURING THE INITIAL PROJECT AND THE PROJECT EXTENSION.

GRADE	PIPE NO	FIBERIZATION	FIBRE RATIO (%)	THICKNESS cm	BURSTING PRESSURE MPa	PRESSURE PER UNIT THICKNESS MPa/cm	CLASS
AK	REF	WILLOW	16	2.05	>4.8	>2.34	200
AK-100	17	WILLOW	16	2.18	>4.8	>2.20	200
	18R	WILLOW	16	1.51	2.7	1.79	150
AX	31	WILLOW	14	2.19	>4.8	>2.19	200
	8*	WILLOW	16	1.85	4.1	2.22	150
	34	WILLOW	18	2.19	>4.8	>2.19	200
	30	PALLMANN	16	1.30	2.7	2.08	150
	30R	PALLMANN	16	2.06	4.1	1.99	150
AX-100	20	WILLOW	16	2.38	4.2	1.76	150
WX	22	AS RECEIVED	14	2.05	1.2	0.59	(a)
	13*	AS RECEIVED	16	1.88	>4.8	>2.55	200
	24	AS RECEIVED	18	1.44	2.5	1.74	150
	24R	AS RECEIVED	18	1.83	3.6	1.97	150
	25	PALLMANN	16	1.55	2.7	1.74	150
	25R	PALLMANN	16	1.75	3.2	1.83	150
	27	TURBINE	16	1.86	0.7	0.38	(a)
WZ	36	AS RECEIVED	14	1.63	2.8	1.72	150
	37	AS RECEIVED	18	2.34	2.7	1.15	100
	40	TURBINE	16	1.70	0.8	0.47	(a)
4T	10*	WILLOW	16	1.95	>4.8	>2.46	200

CONTROL LIMITS FOR 8- in (20.3-cm)PIPE

---	---	---	---	1.97 TO 2.12	2.4	1.14	100
---	---	---	---	1.97 TO 2.12	3.6	1.71	150
---	---	---	---	1.97 TO 2.12	4.8	2.28	200

* DATA FROM INITIAL PROJECT

(a) INSUFFICIENT THICKNESS (less than ¾") as a classification criteria. However, it must be noted that three of the pipes in Class 150 might have reached Class 200 if the hydrostatic apparatus was able to exceed pressures of 4.8 MPa since the three pipes in question could not be burst at that pressure.

PIPE CLASSIFICATION:

The combined classification of the pipes taking into account the crushing and hydrostatic resistance of the pipes from both the initial project and the project extension is presented in Table 26. From that table, the best results are summarized hereunder.

GRADE	FIBER-IZATION	FIBRE RATIO %	PIPE No.	THICK-NESS cm	BASED UPON RESISTANCE TO:		
					CRUSHING CLASS	HYDROSTATIC CLASS	OVERALL CLASS
AK	Willow	16	12*	1.93	200	200	200
AK-100	Willow	16	17	2.18	200	200	200
AX	Willow	14	31	2.19	150	200	150
		18	33	2.24	200	--	--
AX-100	Willow	16	19	1.62	150	--	150
			20	2.38	--	150	--
WX	as received	16	13*	1.88	--	200	150
			14*	1.29	150	--	--
WZ	as received	14	35	2.40	150	--	150
			36	1.63	--	150	
4T	Willow	16	10*	1.95	150	200	150

* Data from the initial project

TABLE 26

CLASSIFICATION OF PIPES PRODUCED FROM BOTH THE INITIAL PROJECT AND THE PROJECT EXTENSION BASED ON CRUSHING AND HYDROSTATIC RESISTANCE.

					RESISTANCE PER UNIT THICKNESS				
					CRUSHING		BURSTING		CLASSIFICATION
GRADE	PIPE No	FIBERIZATION	FIBRE RATIO (%)	THICKNESS cm	kN/m.cm	CLASS	MPa/cm	CLASS	CLASS
AK	11#	WILLOW	16	1.95	69.1	200	---	---	200
	12#	WILLOW	16	1.93	74.9	200	2.49	200	200
	REF	WILLOW	16	2.05	75.9	200	2.34	200	200
AK-100	17	WILLOW	16	2.18	67.8	200	>2.20	200	200
	18	WILLOW	16	1.39	46.1	150	---	---	150
	18R	WILLOW	16	1.51	---	---	1.79	150	150
AX	31	WILLOW	14	2.19	62.0	150	>2.19	200	150
	32	WILLOW	14	2.25	57.2	150	---	---	150
	7#	WILLOW	16	1.49	51.2	150	---	---	150
	8#	WILLOW	16	1.85	---	---	2.22	150	150
	33	WILLOW	18	2.24	66.1	200	---	---	200
	34	WILLOW	18	2.19	58.5	150	---	---	150
	29	PALLMANN	16	1.71	43.3	150	>2.19	200	150
	30	PALLMANN	16	1.30	---	---	2.08	150	150
	30R	PALLMANN	16	2.06	---	---	1.99	150	150
AX-100	19	WILLOW	16	1.62	59.2	150	---	---	150
	20	WILLOW	16	2.38	---	---	1.76	150	150
WX	21	AS RECEIVED	14	1.85	40.6	150	---	---	150
	22	AS RECEIVED	14	2.05	---	---	0.59	(a)	(a)
	13#	AS RECEIVED	16	1.88	---	---	>2.55	200	200
	14#	AS RECEIVED	16	1.29	44.2	150	---	---	150
	23	AS RECEIVED	18	1.95	36.0	100	---	---	100
	24	AS RECEIVED	18	1.44	---	---	1.74	150	150
	24R	AS RECEIVED	18	1.83	---	---	1.97	150	150
	25	PALLMANN	16	1.55	---	---	1.74	150	150
	25R	PALLMANN	16	1.75	---	---	1.93	150	150
	26	PALLMANN	16	1.95	41.4	150	---	---	150
	27	TURBINE	16	1.86	---	---	0.38	(a)	(a)
	28	TURBINE	16	1.86	34.2	100	---	---	100
WZ	35	AS RECEIVED	14	2.40	50.5	150	---	---	150
	36	AS RECEIVED	14	1.63	---	---	1.72	150	150
	37	AS RECEIVED	18	2.34	---	---	1.15	100	100
	38	AS RECEIVED	18	1.51	49.9	150	---	---	150
	38R	AS RECEIVED	18	2.02	39.2	150	---	---	150
	39	TURBINE	16	1.59	31.2	100	---	---	100
	40	TURBINE	16	1.70	---	---	0.47	(a)	(a)
4T	10#	WILLOW	16	1.95	53.7	150	2.45	200	150

CONTROL LIMITS FOR 8-in (20.3-cm)PIPE

---	---	---	---	1.97 TO 2.12	27.5	100	1.13	100	100
---	---	---	---	1.97 TO 2.12	37.8	150	1.70	150	150
---	---	---	---	1.97 TO 2.12	64.1	200	2.26	200	200

DATA FROM INITIAL PROJECT

(a) INSUFICIENT THICKNESS (less than 0.5in.)

CONCLUSIONS

CONCLUSIONS REGARDING PHASE 3, PART 1, (FSU):

The Fibre Strength Unit ranking of the fibres evaluated was as follows:

GRADE	FIBERIZATION	FSU, UNITS
AK-100	Willow	112
AK	Willow	108
AX-100	Willow	105
WX	as received	101
4T	Willow	85.5
WZ	as received	85.4
AX	Willow	60.0

The above results may be verified by comparing against the results predicted by geometric mean fibre lengths presented in Table 13 by means of the following relationship:

$$FSU- 23 \ln (\text{geometric mean, } \mu m) -51$$

The actual and predicted results are shown hereunder:

			GEOMETRIC MEAN	FIBRE RATIO	FIBRE STRENGTH UNIT	
GRADE	FIBERIZATION	PROJECT	μm	%	PREDICTED UNITS	ACTUAL UNITS
AK-100	Willow	extension	1167	9.0	111.4	112
AK	Willow	initial	1075	9.3	109.5	108
AX-100	Willow	extension	519	10.0	92.8	105
WX	as received	initial	643	9.9	97.7	101
4T	Willow	both	410	11.7	87.4	85.5
WZ	as received	initial	235	11.7	74.6	85.4
AX	Willow	initial	538	16.1	93.6	62.0

The only anomalous result appears to be that for the AX fibre.

On the basis of Fibre Strength Unit evaluation the wet milled grades WX and WZ appear inferior to the AK-100, AK and AX-100. However, they are equal to or better than the 4T and the AX.

CONCLUSIONS WITH REGARD TO PHASE 3, PART 2 (AUTOCLAVED SHEETS):

CONCLUSIONS ON RUNABILITY:

Excellent runability was experienced in all cases. The white water concentrations obtained were excellent in every case when the fibre ratios are taken into account and the wet milled grades were better than average in 6 out of 7 production runs.

CONCLUSIONS ON MR_T:

The flexural moduli of rupture as tested (MR_T) can be compared between grades only when the fibre ratios are equal and the modes of fiberization are comparable. The available data permits comparisons between dry milled fibres fiberized by one pass in a Willow against wet milled fibres as received at 8,10,14 and 18% fibre ratio:

MR_T at 8% fibre:

			FLEXURAL MODULI OF RUPTURE AS TESTED (MR_T) AT 8% FIBRE					
			NON PRESSED			PRESSED		
GRADE	PROJECT	FIBERIZATION	CROSS DIRECTION MPa	MACHINE DIRECTION MPa	AVG MPa	CROSS DIRECTION MPa	MACHINE DIRECTION MPa	AVG MPa
AK	initial	Willow	23.7	32.8	28.3	36.5	48.5	42.5
AK-100	extension	Willow	23.1	34.8	28.9	38.4	54.2	46.3
Dry-milled	average	Willow	23.4	33.8	28.6	37.5	51.4	44.4
WX	initial	as received	24.4	31.6	28.0	32.5	42.2	37.4

The results obtained at the 8% fibre level indicate that the WX wet milled fibre is only slightly (2%) weaker than the dry milled AK and AK-100 for non pressed products, and 16% weaker for pressed products.

The following ratios of the modulus of rupture as tested (MR_T) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION AT 8% FIBRE NON PRESSED	 PRESSED
AK	1.38	1.33
AK-100	1.51	1.41
WX	1.30	1.30

It is apparent that with regard to anisotropy, the wet milled fibre is better for both pressed and unpressed products, at 8% fibre.

MR_T AT 10% FIBRE:

At the 10% fibre level, the following data are available:

FLEXURAL MODULI OF RUPTURE AS TESTED(MR_T), MPa AT 10% FIBRE

			NON PRESSED			PRESSED		
GRADE	PROJET	FIBERIZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
WZ	initial	as recei.	30.4	33.1	31.8	37.0	45.2	41.1
4T	both	Willow	18.8	24.2	21.5	27.2	35.8	31.5

These results (obtained at the 10% fibre level) indicate that the WZ wet milled fibre yielded superior test results for both non pressed (+32%), and pressed (+23%) products. The following ratios of the modulus of rupture as tested (MR_T) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION, AT 10% FIBRE NON PRESSED	 PRESSED
WZ	1.09	1.22
4T	1.29	1.32

It is apparent that the anisotropy of the wet milled fibre is better for both pressed and unpressed products at 10% fibre.

MR_T at 14% fibre:

At the 14% fibre level, the following data are available:

			FLEXURAL MODULI OF RUPTURE AS TESTED(MR_T), MPa AT 14% FIBRE					
			NON PRESSED			PRESSED		
GRADE	PROJET	FIBER-IZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX-100	ext.	Willow	23.5	38.7	31.1	35.5	47.0	41.2
AX	init.	Willow	23.8	32.0	27.9	35.7	48.1	41.9
AX	ext.	Willow	22.9	34.1	28.5	36.1	56.3	46.2
Dry milled	avg.	Willow	23.4	34.9	29.2	35.8	50.5	43.1
WX	ext.	as recei.	30.5	39.5	35.0	48.0	57.6	52.8
WZ	ext.	as recei.	29.9	35.2	32.6	46.6	55.9	51.3
Wet milled	avg.	as recei.	30.2	37.4	33.8	47.3	56.8	52.1

These results (obtained at the 14% fibre level) indicate that the wet milled fibres yield superior test results for both non pressed (+16%), and pressed (+21%) products. The following ratios of the modulus of rupture as tested (MR_T) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION, AT 14% FIBRE	
	NON PRESSED	PRESSED
AX-100	1.65	1.32
AX	1.34	1.35
AX	1.49	1.56
Dry milled,avg	1.49	1.41
WX	1.30	1.20
WZ	1.18	1.20
Wet milled,avg	1.24	1.20

Again the anisotropy of the wet milled fibres is better for both pressed and non pressed products at 14% fibre.

MR_T at 18% fibre:

At the 18% fibre level, the following data are available:

FLEXURAL MODULI OF RUPTURE AS TESTES(MR_T), MPa
AT 14% FIBRE

			NON PRESSED			PRESSED		
GRADE	PROJET	FIBER- IZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX	ext.	Willow	26.8	38.0	32.4	45.0	59.7	52.4
WX	ext.	as recei.	27.3	35.8	31.5	44.3	54.5	50.4
WZ	ext.	as recei.	28.9	38.4	33.6	48.8	60.2	54.5

			FLEXURAL MODULI OF RUPTURE AS TESTES(MR_T),MPa AT 14% FIBRE					
			NON PRESSED			PRESSED		
GRADE	PROJET	FIBERIZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
Wet milled avg		as recei.	28.6	37.1	32.6	46.6	57.4	52.5

These results (obtained at 18% fibre) indicate that the wet milled fibres yield very slightly superior test results for both pressed and non pressed products, but results are not significantly different. The following ratios of the modulus of rupture as tested (MR_T) for machine versus cross directions were obtained:

	MACHINE/CROSS DIRECTION, AT 14% FIBRE	
GRADE	NON PRESSED	PRESSED
AX	1.42	1.33
WX	1.31	1.23
WZ	1.33	1.23
Wet milled, avg	1.30	1.23

The anisotropy of the wet milled fibres is again better for both pressed and non pressed products at 18% fibre.

EFFECT OF METHOD OF FIBERIZATION ON FLEXURAL PERFORMANCE OF SHEETS:

EFFECT OF FIBERIZATION ON MR_T:

The following data on modulus of rupture as tested (MR_T) is available to allow a comparison of the various methods of fiberization:

MODULI OF RUPTURE AS TESTED (MR_T), MPa

				NON PRESSED			PRESSED		
GRADE	PROJET	FIBERIZATION	FIBRE %	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX	ext.	Willow	14	22.9	34.1	28.5	36.1	56.3	46.2
			18	26.8	38.0	32.4	45.0	59.7	52.4
	avg.	Willow	16	24.9	36.1	30.5	40.6	58.0	49.3
	ext.	Pallmann	16	27.3	33.7	30.5	45.6	55.7	50.7
	diff.	Pallmann	16	+ 9.6%	-6.6%	0.0%	+13.8%	- 4.0%	+2.8%
WX	ext.	as recei.	14	30.5	39.5	35.0	48.0	57.6	52.8
			18	27.3	35.8	31.5	44.3	54.5	50.4
	avg	as recei.	16	28.9	37.7	33.3	46.2	56.1	51.2
	ext.	Pallmann	16	29.6	38.8	34.2	53.6	66.4	60.0
	diff.	Pallmann	16	+2.4%	+2.9%	+2.7%	+16.0%	+18.4%	+17.2%
	ext.	turbine	16	32.9	38.2	35.5	52.8	63.5	58.2
	diff.	turbine	16	+13.8%	+ 1.3%	+ 6.6%	+14.3%	+13.2%	+13.7%
WZ	ext.	as recei.	14	29.9	35.2	32.6	46.6	55.9	51.3
			18	28.9	38.4	33.6	48.8	60.2	54.5
	avg	as recei.	16	29.4	36.8	33.1	47.7	58.1	52.9
	ext.	turbine	16	32.7	35.2	33.9	48.0	55.9	51.9
	diff.	turbine	16	+11.2%	- 3.4%	+ 2.4%	0.6%	-3.8%	-1.9%

Since there is no data at 16% fibre for fiberization in the Willow, or as received, the average between results for 14 and 18% fibre must be used. On that basis, it is observed that Pallmann fiberization yielded moduli of rupture ranging between -6.6 and +13.8% higher than Willow fiberization in the case of the AX dry milled fibre, and ranging between +2.4 and +18.4% higher than the as received fibre in the case of the WX wet milled fibre. On the same basis it is observed that turbine fiberization yielded results ranging between +1.3 and +14.3% higher than the as-received fibre in the cases of the WX and ranging between -3.8 and +11.2% higher than the as-received WZ fibre. It is concluded that the Pallmann and turbine fiberizations did not yield the anticipated improvement in about half the cases.

EFFECT OF FIBERIZATION ON ANISOTROPY OF MR_T:

The following ratios of the modulus of rupture as tested (MR_T) for machine versus cross directions were obtained:

		MACHINE/CROSS DIRECTION, AT 14% FIBRE	
GRADE	FIBERIZATION	NON PRESSED	PRESSED
AX	Willow	1.45	1.43
	Pallmann	1.23	1.22
WX	as received	1.30	1.21
	Pallmann	1.31	1.24
	turbine	1.16	1.20
WZ	as received	1.25	1.22
	turbine	1.08	1.16

The anisotropy is better with Pallmann fiberization for the AX but slightly worse for the WX fibre. Turbine fiberization is better for both the WX and WZ.

CONCLUSIONS ON MR_A:

When the flexural moduli of rupture adjusted (MR_A) to a reference density of 1.6g/cm³ are considered, the available data permits comparisons between dry milled fibres fiberized by one pass in a Willow against wet milled fibres as received at 8, 10, 14 and 18% fibre ratios.

MR_A at 8% fibre:

The following data was obtained at 8% fibre ratio:

ADJUSTED FLEXURAL MODULI OF RUPTURE (MR_A) AT 8% FIBRE

			NON PRESSED			PRESSED		
GRADE	PROJET	FIBERIZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AK	initial	Willow	33.6	46.5	40.0	37.5	49.7	43.6
AK-100	ext.	Willow	32.5	48.9	40.7	39.4	55.6	47.5
Dry milled	avg	Willow	33.0	47.7	40.3	38.4	52.6	45.5
WX	initial	as recei.	29.8	38.6	34.2	30.6	39.8	35.2

The results obtained at the 8% fibre level indicate that the WX wet milled fibre is 15.1% weaker than the dry milled AK and AK-100 for non pressed products, and 22.6% weaker for pressed products.

The following ratios of the adjusted modulus of rupture (MR_A) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION, AT 8% FIBRE NON PRESSED	PRESSED
AK	1.38	1.32
AK-100	1.50	1.41
WX	1.29	1.30

It is apparent that with regard to anisotropy, the wet milled fibre is better for both pressed and unpressed products, at 8% fibre.

MR_A at 10% fibre:

At the 10% fibre level, the following data are available:

ADJUSTED FLEXURAL MODULI OF RUPTURE (MR_A) AT 10% FIBRE

			NON PRESSED			PRESSED		
GRADE	PROJECT	FIBER-IZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
WZ	intial	as recei.	33.1	36.0	34.5	31.2	38.0	34.6
4T	both	Willow	29.0	37.2	33.1	30.3	40.0	35.1

These results (obtained at the 10% fibre level) indicate that the WZ wet milled fibre yield equivalent results for both non pressed and pressed products. The following ratios of the adjusted modulus of rupture (MR_A) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION, AT 10% FIBRE NON PRESSED	PRESSED
WZ	1.09	1.22
4T	1.28	1.32

It is apparent that the anisotropy of the wet milled fibre is better for both pressed and unpressed products at 10% fibre.

MR_A at 14% fibre:

At the 14% fibre level, the following data are available:

ADJUSTED FLEXURAL MODULI OF RUPTURE (MR_A) AT 10% FIBRE

			NON PRESSED			PRESSED		
GRADE	PROJECT	FIBER-IZATION	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX-100	ext.	Willow	30.7	50.7	40.7	32.8	43.5	38.1
AX	init.	Willow	32.1	43.2	37.6	35.3	47.6	41.4
AX	ext.	Willow	32.1	47.8	39.9	37.0	57.6	47.3
Dry milled	avg.	Willow	31.6	47.2	39.4	35.0	49.6	42.3
WX	ext.	as recei.	41.1	53.3	47.2	47.7	57.3	52.5
WZ	ext.	as recei.	40.7	47.9	44.3	46.3	55.6	50.9
Wet milled	avg.	as recei.	40.9	50.6	45.7	47.0	56.4	51.7

These results (obtained at the 14% fibre level)indicate that the wet milled fibres yield superior test results for both non pressed (+16%), and pressed (22%) products. The following ratios of the adjusted modulus of rupture (MR_A) for machine versus cross directions were obtained:

GRADE	MACHINE/CROSS DIRECTION, AT 10% FIBRE	
	NON PRESSED	PRESSED
AX-100	1.65	1.33
AX	1.35	1.35
AX	1.49	1.56
Dry milled,avg	1.49	1.42
WX	1.30	1.20
WZ	1.18	1.20
Wet milled,avg	1.24	1.20

Again the anisotropy of the wet milled fibres is better for both pressed and non pressed products at 14% fibre.

MR_A at 18% fibre:

At the 18% fibre level, the following data are available:

ADJUSTED FLEXURAL MODULI OF RUPTURE (MR_A) AT 18% FIBRE

GRADE	PROJECT	FIBERIZATION	NON PRESSED			PRESSED		
			CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX	extension	Willow	40.8	57.9	49.3	47.6	63.0	55.3
WX	extension	as received	39.6	51.9	45.7	45.6	56.0	50.8
WZ	extension	as received	43.1	57.2	50.1	51.4	63.4	57.4
Wet milled avg		as received	41.3	54.5	47.9	48.5	59.7	54.1

These results (obtained at 18% fibre) indicate that the wet milled fibres yield very slightly inferior test results for both non pressed and pressed products, but results are not significantly different. The following ratios of the adjusted modulus of rupture (MR_A) for machine versus cross directions were obtained:

MACHINE/CROSS DIRECTION, AT 10% FIBRE

GRADE	NON PRESSED	PRESSED
AX	1.42	1.32
WX	1.31	1.23
WZ	1.33	1.23
Wet milled,avg	1.32	1.23

The anisotropy of the wet milled fibres is again better for both pressed and non pressed products at 18% fibre.

EFFECT OF FIBERIZATION ON MR_A:

The following data on modulus of rupture adjusted to a reference density (MR_A) is available to allow a comparison of the various methods of fiberization:

MODULI OR RUPTURE ADJUSTED (MR_A), MPa

				NON PRESSED			PRESSED		
GRADE	PROJECT	FIBER-IZATION	FI-BRE %	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
AX	ext.	Willow	14	32.1	47.8	39.9	37.0	57.6	47.3
			18	40.8	57.9	49.3	47.6	63.0	55.3
	avg.	Willow	16	36.4	52.8	44.6	42.3	60.3	51.3
	ext.	Pallmann	16	37.3	46.1	41.7	42.9	52.4	47.6
	diff.	Pallmann	16	+2.5%	-12.7%	- 6.5%	+1.4%	-13.1%	- 7.2%

MODULI OF RUPTURE ADJUSTED (MR_A), MPa

				NON PRESSED			PRESSED		
GRADE	PROJECT	FIBERIZATION	FIBRE %	CROSS DIRECTION	MACHINE DIRECTION	AVG	CROSS DIRECTION	MACHINE DIRECTION	AVG
WX	exten.	as recei.	14	41.1	53.3	47.2	47.7	57.3	52.5
			18	39.6	51.9	45.7	45.6	56.0	50.8
	avg	as recei.	16	40.3	52.6	46.4	46.6	56.6	51.6
	exten.	Pallmann	16	44.4	58.2	51.3	53.2	65.9	59.5
	diff.	Pallmann	16	+10.2%	+10.6%	+10.6%	+14.2%	+16.4%	+15.3%
	exten.	turbine	16	45.4	52.8	49.1	51.7	62.2	56.9
	diff.	turbine	16	+12.7%	+0.4%	+5.8%	+10.9%	+ 9.9%	+10.3%
WZ	exten.	as recei.	14	40.7	47.9	44.3	46.3	55.6	50.9
			18	43.1	57.2	50.1	51.4	63.4	57.4
	avg	as recei.	16	41.9	52.5	47.2	48.8	59.5	54.1
	ext.	turbine	16	46.3	49.8	48.0	49.1	57.2	53.1
	diff	turbine	16	+10.5%	- 5.1	+ 1.7%	+ .6%	- 3.9	- 1.8%

Since there is no data at 16% fibre for fiberization in the Willow, or as received, the average between results for 14 and 18% fibre must be used. On that basis it is observed that Pallmann fiberization yielded moduli of rupture ranging between -13.1 and +2.5% higher than Willow fiberization in the case of the AX dry milled fibre, and ranging between +10.2 and +16.4% higher than the as-received fibre in the case of the WX wet milled fibre. On the same basis, it is observed that turbine fiberization yielded results ranging between +0.4 and +12,7% higher than the as-received fibre in the cases of the WX, and ranging between -5.1 and +10.5% higher than the as-received WZ fibre. It is concluded that the Pallmann and turbine fiberizations did not yield the anticipated improvement in about half the cases.

EFFECT OF FIBERIZATION ON ANISOTROPY OF MR_A:

The following ratios of the adjusted modulus of rupture (MR_A) for machine versus cross directions were obtained:

GRADE	FIBERIZATION	MACHINE/CROSS DIRECTION, AT 10% FIBRE NON PRESSED	PRESSED
AX	Willow	1.45	1.43
	Pallmann	1.24	1.22
WX	as received	1.30	1.21
	Pallmann	1.31	1.24
	turbine	1.16	1.20
WZ	as received	1.25	1.22
	turbine	1.08	1.16

The anisotropy is better with Pallmann fiberization for the AX but slightly worse for the WX fibre. Turbine fiberization is better for both the WX and WZ.

EFFECT OF FIBRE CONTENT ON MR_T:

The effect of fibre ratio on the modulus of rupture as tested (MR_T) is presented in Table 27 for fibre ratios ranging between 8 and 18%. If the grand average for pressed and non pressed products tested in the

TABLE 27

MODULI OF RUPTURE AS TESTED (MRt) SHOWING THE EFFECT OF FIBRE RATIO (Qf),IN MPa.

				NON PRESSED			PRESSED			
GRADE	PROJECT	FIBERIZATION	(Qf) FIBRE (%)	MACHINE DIRECTION	CROSS DIRECTION	AVG	MACHINE DIRECTION	CROSS DIRECTION	AVG	GRAND AVG
AX	INITIAL	WILLOW	14	32.0	23.8	27.9	48.1	35.7	41.9	34.9
	EXTENSION	WILLOW	14	34.1	22.9	28.5	56.3	36.1	46.2	37.4
	EXTENSION	PALLMANN	16	33.7	27.3	30.5	55.7	45.6	50.7	40.6
	EXTENSION	WILLOW	18	38.0	26.8	32.4	59.7	45.0	52.4	42.4
MX	INITIAL	AS RECEIVED	8	31.6	24.4	28.0	42.2	32.5	37.4	32.7
	EXTENSION	AS RECEIVED	14	39.5	30.5	35.0	57.6	48.0	52.8	43.9
	EXTENSION	PALLMANN	16	38.8	29.6	34.2	66.4	53.6	60.0	47.1
	EXTENSION	TURBINE	16	38.2	32.9	35.6	63.5	52.8	58.2	46.9
	EXTENSION	AS RECEIVED	18	35.8	27.3	31.6	54.5	44.3	49.4	40.5
WX	INITIAL	AS RECEIVED	10	33.1	30.4	31.8	45.2	37.0	41.1	36.4
	EXTENSION	AS RECEIVED	14	35.2	29.9	32.6	55.9	46.6	51.3	41.9
	EXTENSION	TURBINE	16	35.2	32.7	34.0	55.9	48.0	52.0	43.0
	EXTENSION	AS RECEIVED	18	38.4	28.9	33.7	60.2	48.8	54.5	44.1

machine and cross directions is considered, it is apparent that MR_T is a function of fibre ratio for the AX and WZ grades whereas for the WX grade the optimum fibre ratio appears to be 16% fibre. A graph of MR_A as a function of Qf is presented in Fig. 15.

EFFECT OF FIBRE CONTENT ON MR_A:

The effect of fibre ratio on the modulus of rupture adjusted to a reference density of 1.6g/cm³ (MR_A) is presented in Table 28. If the grand average for pressed and non pressed products tested in the machine and cross directions is considered, it is apparent that MR_A is again a function of fibre ratio for the AX and WZ grades whereas for the WX grade the optimum fibre ratio appears to be 16% fibre. A graph of MR_A as a function of Qf is presented in Fig. 16.

COMPARATIVE FIBRE EFFICIENCIES:

When fibre efficiency is defined as the quotient of the grand average MR_A (modulus of rupture adjusted to the reference density of 1.6g/cm³) per unit fibre ratio, the following efficiencies are obtained:

FIBRE %	GRADE	PROJECT	FIBERIZATION	EFFICIENCY, MR_A/Qf MPa/%
8	AK	initial	Willow	5.2
	AK-100	extension	Willow	5.5
	WX	initial	as received	4.3
10	4T	initial	Willow	3.4
	WZ	initial	as received	3.5
14	AX-100	extension	Willow	2.8
	AX	extension	Willow	2.8

Fig. 15

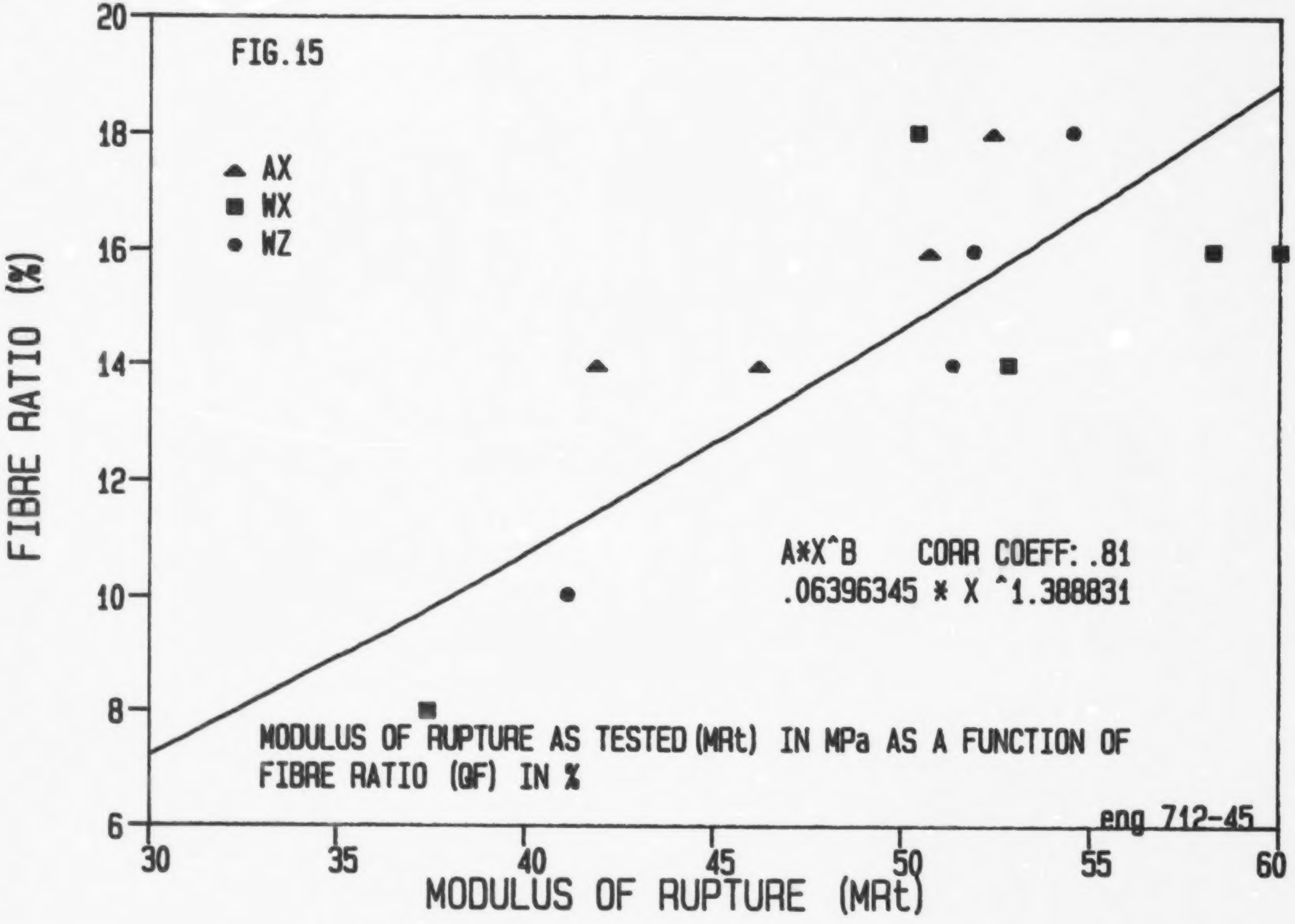


FIG.15

MODULUS OF RUPTURE AS TESTED (MRt) IN MPa AS A FUNCTION OF FIBRE RATIO (QF) IN %

A*X^B CORR COEFF: .81
.06396345 * X ^1.388831

MR$_T$ Fig. 15

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     X            A+(B*X)        A*EXP(B*X)      A+B*LOG(X)        A*X^B             Y
 ----------     -----------     -----------     -----------     -----------      ---------

 37.4          10.41082        10.16655        9.943176        9.781018          8
 41.1          11.70011        11.27594        11.56962        11.15025          10
  1.9          11.97888        11.53129        11.90197        11.45282          14
  6.2          13.47725        13.0062         13.58629        13.11709          14
 52.8          15.77708        15.64527        15.88846        15.78988          14
 51.3          15.25439        15.00198        15.39158        15.17034          14
  0.7          15.04532        14.75213        15.18873        14.92447          16
 60            18.28598        19.13857        18.09238        18.85743          16
 58.2          17.65876        18.19818        17.56726        18.07636          16
  1.9          15.46347        15.25606        15.59205        15.41732          16
 52.4          15.6377         15.47108        15.75734        15.62398          18
 50.4          14.94078        14.62876        15.08641        14.80197          18
  4.5          16.36946        16.40775        16.4348         16.50033          18

A REG COEFF   -2.621535        3.568803       -52.49682        6.396345E-02
B REG COEFF    .3484586        2.799126E-02    17.24066        1.388831
  STD ERROR    4.419867        1.214167        15.51142        7.557105E-02
B STD ERROR    8.785158E-02    6.762329E-03    3.973354        .3026421
A T-STAT      -.5931254        3.739467       -3.384398       -2.327133
  T-STAT       3.966447        4.139293        4.33907         4.58902
  D ERR EST    2.012835        .1549369        1.905553        .145142
R-SQUARED      .588519         .6090105        .6312131        .6568838
  VARIANCE     15.24359        1.224499        .3304457        2.661923E-02
  TEST         15.7327         17.13375        18.82753        21.0591
CORR COEFF     .76715          .7803913        .7944893        .8104837
DURBN-WATSN    1.090842        1.204207        1.128378        1.225161
```

MR$_A$ Fig. 16

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     X            A+(B*X)        A*EXP(B*X)      A+B*LOG(X)        A*X^B             Y
 ----------     -----------     -----------     -----------     -----------      ---------

  4.7          10.43973        10.25089        10.14023        9.995252          8
 34.6          10.40371        10.22178        10.09359        9.95835           10
 39.6          12.20421        11.7833         12.27491        11.83901          14
  3.6          13.64461        13.20259        13.83005        13.39295          14
 49.9          15.91324        15.79253        16.01119        15.92199          14
 47.6          15.08501        14.79283        15.24858        14.98761          14
  4.7          14.04072        13.62203        14.23272        13.82753          16
  5.4          17.89379        18.4657         17.70094        18.2052           16
 53            17.02955        17.24768        16.98522        17.20065          16
 50.6          16.16531        16.10999        16.23631        16.20882          16
  2.3          16.77748        16.90779        16.77035        16.91003          18
 47.6          15.08501        14.79283        15.24858        14.98761          18
 53.8          17.31763        17.64449        17.22733        17.5341           18

  REG COEFF   -2.055736        3.821949       -47.17827        .1060871
  REG COEFF    .3600997        .0284324        16.1609         1.281629
  STD ERROR    3.412441        1.030145        11.54858        9.565034E-02
  STD ERROR    7.230207E-02    5.710827E-03    3.010435        .2350307
  T-STAT      -.6024239        4.974367       -4.085201       -2.488291
  T-STAT       4.98049         4.978684        5.368293        5.453029
  D ERR EST    1.739226        .1373739        1.649251        .1287603
R-SQUARED      .6927828        .6926283        .723747         .7299654
COVARIANCE     17.3641         1.371018        .4042027        3.205503E-02
  TEST         24.80528        24.78729        28.81857        29.73552
  RR COEFF     .8323358        .832243         .8507331        .8543801
DURBN-WATSN    1.570996        1.779206        1.53177         1.740585
```

TABLE 28

MODULI OF RUPTURE ADJUSTED TO A REFERENCE DENSITY OF 1.6 g/cm3 (MPa)
SHOWING THE EFFECT OF FIBRE RATIO (Qf), IN MPa.

				NON PRESSED			PRESSED			
GRADE	PROJECT	FIBERIZATION	(Qf) FIBRE (%)	MACHINE DIRECTION	CROSS DIRECTION	AVG	MACHINE DIRECTION	CROSS DIRECTION	AVG	GRAND AVG
AX	INITIAL	WILLOW	14	43.2	32.1	37.7	47.6	35.3	41.5	39.6
	EXTENSION	WILLOW	14	47.8	32.1	40.0	57.6	37.0	47.3	43.6
	EXTENSION	PALLMANN	16	46.1	37.3	41.7	52.4	42.9	47.7	44.7
	EXTENSION	WILLOW	18	57.9	40.8	49.4	63.0	47.6	55.3	52.3
WX	INITIAL	AS RECEIVED	8	38.6	29.8	34.2	39.8	30.6	35.2	34.7
	EXTENSION	AS RECEIVED	14	53.3	41.1	47.2	57.3	47.7	52.5	49.9
	EXTENSION	PALLMANN	16	58.2	44.4	51.3	65.9	53.2	59.6	55.4
	EXTENSION	TURBINE	16	52.8	45.4	49.1	62.2	51.7	57.0	53.0
	EXTENSION	AS RECEIVED	18	51.9	39.6	45.8	56.0	45.6	50.8	48.3
WZ	INITIAL	AS RECEIVED	10	36.0	33.1	34.6	38.0	31.2	34.6	34.6
	EXTENSION	AS RECEIVED	14	47.9	40.7	44.3	55.6	46.3	51.0	47.6
	EXTENSION	TURBINE	16	49.8	46.3	48.1	57.2	49.1	53.2	50.6
	EXTENSION	AS RECEIVED	18	57.2	43.1	50.2	63.4	49.1	56.3	53.2

FIG. 16

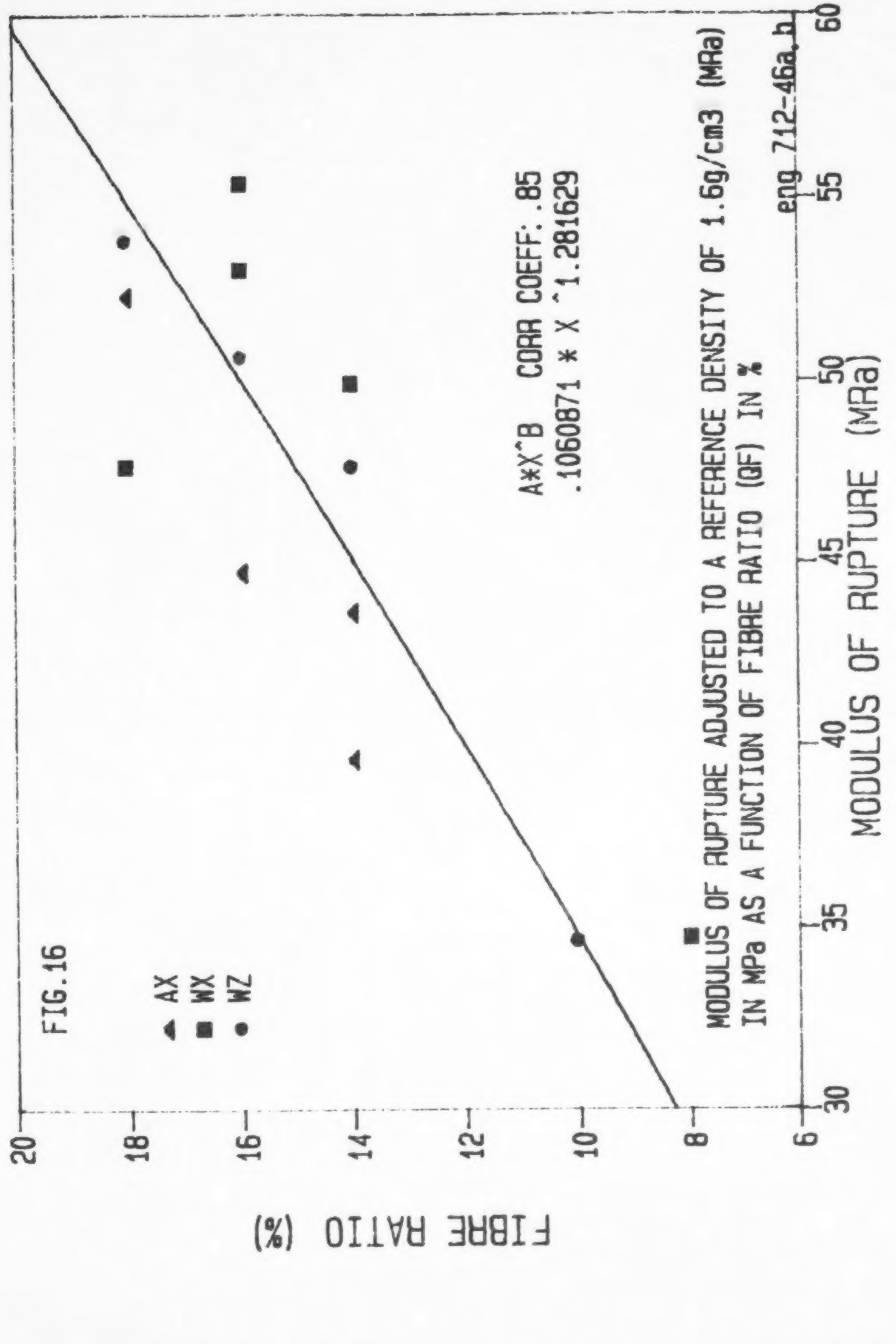
FIG.16
▲ AX
■ WX
● WZ
MODULUS OF RUPTURE ADJUSTED TO A REFERENCE DENSITY OF 1.6g/cm3 (MRa)
IN MPa AS A FUNCTION OF FIBRE RATIO (QF) IN %
A*X^B CORR COEFF: .85
.1060871 * X ^1.281629
eng 712-46a,h
FIBRE RATIO (%)
6
8
10
12
14
16
18
20
30
35
40
45
50
55
60
MODULUS OF RUPTURE (MRa)

FIBRE %	GRADE	PROJECT	FIBERIZATION	EFFICIENCY, MR_A/Qf MPa/%
14		initial	Willow	3.1
	WZ	extension	as received	3.4
	WX	extension	as received	3.6
16	AX	extension	Pallmann	2.8
	WZ	extension	Turbine	3.2
	WX	extension	Turbine	3.3
		extension	Pallmann	3.5
18	WX	extension	as received	2.7
	AX	extension	Willow	2.9
	WZ	extension	as received	3.0

In every case except for the 18% AX fibre, the wet milled grades yielded better efficiencies when compared against dry milled grades at equal fibre ratios.

CONCLUSIONS ON SHEET DENSITIES:

The following sheet product densities were obtained:

				SHEET PRODUCT DENSITIES					
				NON PRESSED		PRESSED		AVERAGE	
GRADE	PROJECT	FIBERIZATION	FIBRE %	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3
AK	init.	Willow	8	1.46	91.1	1.67	104.2	1.57	97.7
AK-100	ext.	Willow	8	1.35	84.2	1.58	98.6	1.47	91.4
AX	init.	Willow	14	1.46	91.1	1.80	112.3	1.63	101.7

				SHEET PRODUCT DENSITIES					
			FI-BRE	NON PRESSED		PRESSED		AVERAGE	
GRADE	PROJECT	FIBER-IZATION	%	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3
AX	ext.	Willow	14	1.35	84.2	1.58	98.6	1.47	91.4
	ext.	Pallmann	16	1.37	85.5	1.65	103.0	1.51	94.2
		Willow	18	1.30	81.1	1.56	97.3	1.43	89.2
AX-100	ext.	Willow	14	1.40	87.4	1.66	103.6	1.53	95.5
WX	init.	as-rec.	8	1.58	98.6	1.81	112.9	1.70	10.58
	ext.	as-rec.	14	1.38	86.1	1.60	99.8	1.49	93.0
		Pallmann	16	1.31	81.7	1.61	100.5	1.46	91.1
		Turbine	16	1.36	84.9	1.62	101.1	1.49	93.0
		as-rec.	18	1.33	83.0	1.59	99.2	1.46	91.1
WZ	init.	as-rec.	10	1.62	101.1	1.87	116.7	1.75	108.9
	exten.	as-rec.	14	1.37	85.5	1.60	99.8	1.49	92.7
		turbine	16	1.34	83.6	1.58	98.6	1.46	91.1
		as-rec.	18	1.31	81.7	1.56	97.3	1.44	89.5
4T	both	Willow	10	1.41	88.0	1.65	103.0	1.53	95.5

If the above data is re-arranged to compare only dry milled fibre fiberized in a Willow versus wet milled fibre as received on the basis of equal fibre ratios, the following presentation results.

				SHEET PRODUCT DENSITIES					
FI-BRE				NON PRESSED		PRESSED		AVERAGE	
%	GRADE	PROJECT	FIBER-IZATION	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3
8	AK-100	ext.	Willow	1.35	84.2	1.58	98.6	1.47	91.4
	AK	init.	Willow	1.46	91.1	1.67	104.2	1.57	97.7

				SHEET PRODUCT DENSITIES					
				NON PRESSED		PRESSED		AVERAGE	
FI-BRE %	GRADE	PROJECT	FIBER-IZATION	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3	g/cm^3	lb/ft^3
10	4T	both	Willow	1.41	88.0	1.65	103.0	1.53	95.5
	WZ	init.	as-rec.	1.62	101.1	1.87	116.7	1.75	108.9
14	AX	ext.	Willow	1.35	64.2	1.58	98.6	1.47	91.4
	WZ	ext.	as-rec.	1.37	85.5	1.60	99.8	1.485	92.7
	WX	ext.	as-rec.	1.38	86.1	1.60	99.8	1.49	93.0
	AX-100	ext.	Willow	1.40	87.4	1.66	103.6	1.53	95.5
	AX	init.	Willow	1.46	91.1	1.80	112.3	1.63	101.7
18	AX	init.	Willow	1.30	81.1	1.56	97.3	1.43	89.2
	WZ	init.	as-rec.	1.31	81.7	1.56	97.3	1.44	89.5

The wet milled fibres yield comparable densities.

CONCLUSIONS ON SHEET POROSITIES:

The following sheet product porosities were obtained:

GRADE	PROJECT	FIBER-IZATION	FI-BRE %	SHEET PRODUCT DENSITIES		
				NON PRESSED	PRESSED	AVERAGE
AK	init.	Willow	8	29.0	21.0	25.0
AK-100	ext.	Willow	8	35.6	25.8	30.7
AX	init.	Willow	14	23.8	17.8	20.8
	ext.	Willow	14	33.6	25.2	29.4
		Pallmann	16	34.2	22.9	28.6
		Willow	18	36.7	26.0	31.4
AK-100	ext.	Willow	14	31.5	21.8	26.7
WX	init.	as-rec.	8	23.7	17.4	20.6
	ext.	as-rec.	14	33.2	24.6	28.9
		Pallmann	16	36.5	23.6	30.1
		turbine	16	34.6	24.2	29.4
		as-rec.	18	35.6	24.9	30.3
WZ	init.	as-rec.	10	24.8	16.6	20.7
	exten.	as-rec.	14	32.6	23.8	28.2
		turbine	16	35.0	25.3	30.2
		as-rec.	18	36.1	25.9	31.0
4T	both	Willow	10	30.6	20.6	25.6

If the above data is re-arranged to compare only the dry milled fibres fiberized in a Willow against wet milled fibres as received on the basis of equal fibre ratios, the following presentation results:

FIBRE %	GRADE	PROJECT	FIBERIZATION	PRODUCT POROSITIES, % NON PRESSED	PRESSED	AVERAGE
8	AK-100	exten.	Willow	35.6	25.6	30.7
	AK	init.	Willow	29.0	21.0	25.0
	WX	init.	as-rec.	23.7	17.4	20.6
10	4T	both	as-rec.	30.6	20.6	25.6
	WZ	initial	as-rec.	24.8	16.6	20.7
14	AX	exten.	Willow	33.6	25.2	29.4
	WX	exten.	as-rec.	33.2	24.6	28.9
	WZ	exten.	as-rec.	32.6	23.8	28.2
	AX-100	initial	Willow	31.5	21.8	26.7
	AX	initial	Willow	23.8	17.8	20.8
18	AX	extension	Willow	36.7	26.0	31.4
	WZ	extension	as-rec.	36.1	25.9	31.0
	WX	extension	as-rec.	35.6	24.9	30.3

The wet milled fibres yielded comparable porosities.

CONCLUSIONS CONCERNING PHASE 3, PART 3 (PRODUCTION AND TESTING OF PIPES)

RUNABILITY:

When compared against the dry milled fibres, the wet milled fibres gave poor runability, premature mandrel release and plastic deformation as noted in Table 21B. It is concluded that the wet milled fibres cannot be used as 100% of the fibre furnish but must be used as part of a fibre mix including harsher fibre (such as crocidolite) to improve runability.

CONCLUSIONS ON PIPE DENSITIES:

Pipe densities averaging 1.43g/cm^3 (89.2 lb/ft^3) were achieved and this is significantly less than densities for commercial pressure pipes [1.9g/cm^3(119 lb/ft^3)] achieved on industrial scale Hatschek machines. Low densities cannot permit achieving the full potential crushing and hydrostatic resistance. Accordingly, the latter results must be considered as conservative.

CONCLUSIONS ON PIPE POROSITIES:

The pipe porosities obtained average 29.6% and they vary inversely with the densities. Again it is expected that significantly lower porosities would be obtained on full scale industrial Hatschek machines with substantially greater mandrel pressures.

CONCLUSIONS ON PIPE CRUSHING STRENGTH:

The crushing strengths of the pipes are compared hereunder for trials on a given fibre ratio basis:

FIBRE %	GRADE	FIBERIZATION	PIPE No.	CRUSHING STRENGTH PER UNIT THICKNESS kN/m.cm	CLASS
14	AX	Willow	31	62.0	150
			32	57.2	150
	WX	as received	21	40.6	150
	WZ	as received	35	50.5	150
16	AK	Willow	11*	69.1	200
		Willow	12*	74.9	200
		Willow	REF	75.9	200

FIBRE %	GRADE	FIBERIZATION	PIPE No.	CRUSHING STRENGTH PER UNIT THICKNESS kN/m.cm	CLASS
16	AK-100	Willow	17	67.8	200
		Willow	18	46.1	150
	AX	Willow	7*	51.2	150
		Pallmann	29	43.3	150
	AX-100	Willow	19	59.2	150
	WX	as received	14*	44.2	150
		Pallmann	26	41.4	150
		turbine	28	34.2	100
	WZ	turbine	39	31.2	100
	4T	Willow	10*	53.7	150
18	AX	Willow	33	66.1	200
			34	58.5	150
	WX	as received	23	36.0	100
	WZ	as received	38	49.9	150
			38R	39.2	150

* Initial project

At each fibre ratio level the wet milled fibres gave inferior crushing strengths. However, the wet mill fibres as received were sufficient to yield class 150 pipes at 14% fibre level despite the low density.

CONCLUSIONS ON THE HYDROSTATIC STRENGTH OF PIPES:

The hydrostatic resistance of the pipes are compared hereunder for trials on a given fibre ratio basis:

FIBRE %	GRADE	FIBERIZATION	PIPE No.	BURSTING PRESSURE PER UNIT THICKNESS MPa/cm	CLASS
14	AX	Willow	31	>2.14	200
	WX	as received	22	0.59	(a)
	WZ	as received	36	1.72	150
16	AK	Willow	REF	>2.34	200
	AK-100	Willow	17	>2.20	200
			18R	1.79	150
	AX	Willow	8*	2.22	150
		Pallmann	30	2.08	150
			30R	1.99	150
	AX-100	Willow	20	1.76	150
	WX	as received	13*	>2.55	200
		Pallmann	25	1.74	150
		Pallmann	25R	1.83	150
		turbine	27	0.38	(a)
	WZ	turbine	40	0.47	(a)
	4T	Willow	10*	2.46	200
18	AX	Willow	34	>2.19	200
	WX	as received	24	1.74	150
			24R	1.97	150
	WZ	as received	37	1.15	100

* Initial project

(a) Insufficient thickness (less than ½ inch.)

At each fibre ratio level, the wet milled fibres gave inferior bursting strengths. However, the WX as received yielded a class 200 pipe at 16%

fibre and the WZ as received yielded a class 150 pipe at 14% fibre despite the shortfall in density, and in the absence of harsh fibre in the furnish.

GENERAL CONCLUSIONS:

1. On the basis fo Fibre Strength Unit evaluation the wet milled grades WX and WZ appear inferior to the AK-100, AK and AX-100. However, they are equal to or better than the 4T and the AX.

2. When compared as the furnish for flat autoclaved sheets, the wet milled fibres as received yielded generally superior flexural strengths than dry milled fibres fiberized by one pass in a Willow. The anisotropy of sheets produced from the wet milled fibres was significantly better in all cases. With one exception, the efficiencies of the wet milled fibres were superior.

   2.1 Pallmann or turbine fiberization of the wet milled grades gave mixed results and did not yield the anticipated flexural strength improvement, but the ansitropy was improved particularly with turbine fiberization.

   2.2 The WX yielded maximum strength at 16% fibre while the WZ had to yet reached a maximum at 18% fibre.

   2.3 The fibre efficiencies (MR_A/Qf) for wet milled fibres were superior in all cases but one (18% AX).

   2.4 Sheet product densities and porosities were comparable with wet or dry milled fibres.

3. The pipe production trials confirm that the wet milled fibres cannot be used as 100% of the fibre furnish but must be used as part of a fibre mix including harsh fibre to improve runability.

3.1 Pipe densities averaging 1.43g/cm³ (89.2lb/ft³) were achieved and these are significantly lower than commercial products at 1.9g/cm³ (119 lb/ft³).

3.2 Based upon crushing strength the wet milled fibres yield class 150 pipes at 14% fibre despite the low density.

3.3 Based upon bursting strength the WX as received yielded a class 200 pipe at 16% fibre and the WZ yielded a class 150 pipe at 14% fibre despite the low density and absence of harsh fibre.

RECOMMENDATIONS

Evaluate the wet milled fibres as components of a commercial furnish (fibre mix) including fibres that contribute resistance to plastic deformation.